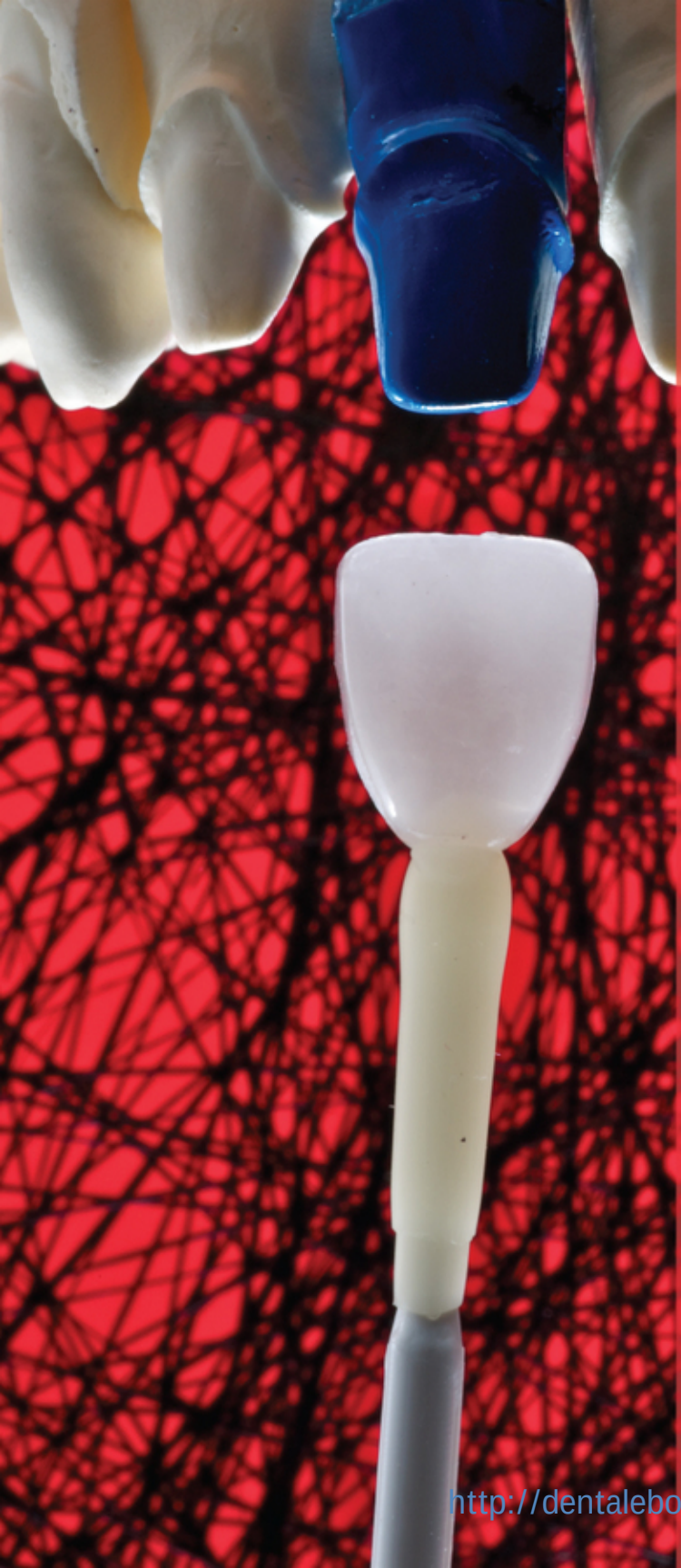

Prosthodontics at a Glance

Irfan Ahmad

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Prosthodontics at a Glance

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For my caring wife, Samar, my shining children Zayan and Zaina,
and my loving father Mansur Ahmad

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What good's a disease that won't hurt you?

Lou Reed

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Preface

In a Utopian context, a tooth should survive throughout life, unscathed by disease or trauma. However, in the real world, a tooth endures vicissitudes, often necessitating clinical intervention for ensuring its viability. Assuming a pessimistic stance, from nascence to its final demise, a tooth may undergo the following pathological sequelae: incipient fissure or proximal caries, intracoronal decay, pronounced multi-surface caries, endodontic involvement, extracoronal restoration, intra- and periradicular compromises with or without periodontal involvement leading to extraction, and eventual replacement by either a denture (removable or fixed) or dental implants. On an optimistic note, it is not a fait accompli that these events are inevitable; clinical intervention at any stage can prevent progression to the next, more destructive, eventuality. All these aforementioned stages require some form of clinical intervention for salvaging or replacing lost teeth. This is the basic premise of prosthodontics.

Prosthodontics is defined as restoring and/or replacing missing teeth. At times, the line dividing restorative dentistry and prosthodontics can be vague. As a generality, restorative dentistry is concerned with restoring teeth directly, involving a single visit, while prosthodontics is restoring or replacing teeth indirectly, invariably involving multiple visits, usually with impression and employing a dental laboratory. Furthermore, prosthodontics is a multidisciplinary subject, involving specialties such as periodontics, endodontics, orthodontics, implantology and oral surgery.

Besides resolving pathology, another factor requiring consideration is vanity. In an ever-increasing appearance-conscious society, elective cosmetic dental treatment is burgeoning. Although, at times, this type of treatment may be questionable, the communication revolution has created immense patient awareness leading to an escalating demand for patient-driven treatment planning. Hence, cosmetic or aesthetic treatment is now a major part of prosthodontics.

The purpose of this book is to describe the main concepts of prosthodontics. Its aim is to act as a platform for further reading on a chosen aspect of prosthodontics. The ordered format of the ‘At a Glance’ series accelerates learning, ensures relevance to daily clinical practice, and avoids the tedium and frustration of a verbose text.

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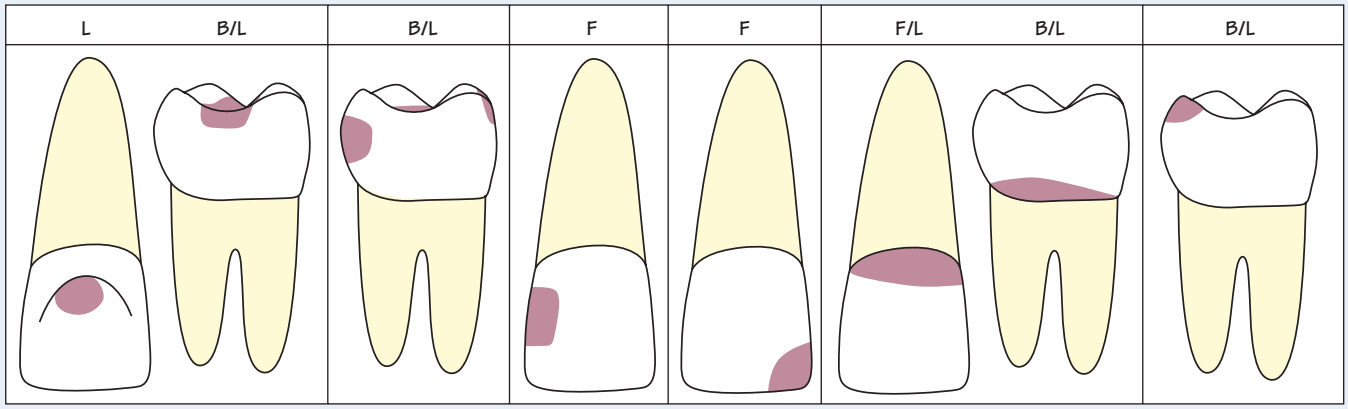
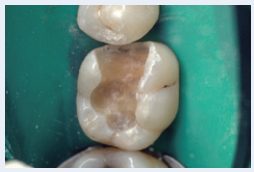
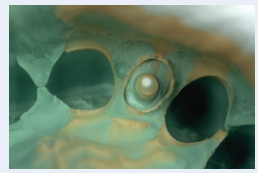
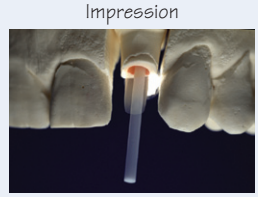
1 Overview: rehabilitation of natural teeth

Black's cavity classification



Key: B (buccal), L (lingual), F (facial)

Inlay	PLV	Crowns	Post-crown
Preoperative	Preoperative	Preoperative	Preoperative
			
Preparation	Wax-up	Preparation	Preparation
			
Impression	Preparation	Temporaries	Impression
			
Fabrication	Fabrication	Fabrication	Fabrication
Postoperative	Postoperative	Postoperative	Postoperative

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An **indirect restoration** requires taking an impression and employing a **dental laboratory** to fabricate the prosthesis. Conversely, a **direct restoration** is carried out chair-side, usually in a single visit, without using a dental laboratory. Dental prostheses can either be **intra**- or **extracoronal.**

Indirect intracoronal prostheses

Intracoronal prostheses are defined as those **surrounded by one or more natural tooth surface(s)**. This categorisation is broadly based on **Black's cavity classification**:

- **Class I**: lesions of pits and fissures of all teeth, predominantly in premolars and molars;
- **Class II**: lesions on the proximal surfaces of posterior teeth, referred to as MO (mesial-occlusal), DO (disto-occlusal), and MOD (mesial-occlusal-distal);
- **Class III**: lesion in the anterior teeth, similar to a class II lesion, the class III lesion typically appears at the contact point;
- **Class IV**: the class IV lesion is a class III lesion including the incisal corner of an anterior tooth;
- **Class V**: typically occurs at the cervical margins on the buccal, rather than the lingual, aspect of any tooth;
- **Class VI**: not originally in Black's classification, but has become accepted as an additional lesion that occurs on the tips and cusps of posterior teeth, or along the biting surfaces of the incisors.

Three developments have made Black's cavity classification **redundant**. First, research has elucidated biological mechanisms such as **demineralisation/remineralisation** and the role of fluoride ion, and removal of infected and affected dentine is no longer a prerequisite. Second, **new restorative materials** such as resin (plastic)-based adhesives and filling materials, and therapeutic filling materials, which are both bacteriostatic and bactericidal, avoid removing vast amounts of tooth. Third, **improved and sophisticated techniques** such as adhesive protocols allow restorations of small lesions, preventing progression to larger cavities. All these advances preserve more of the natural tooth, and Black's classification is therefore used today as a notation, rather than as a basis for restoring decay. Whereas, in the past, cavity design was **geometric** (dictated by the restorative material), it is now **amorphous** (dictated by the extent of disease).

Smaller lesions are restored by a direct approach, while larger Class II or Class IV are restored indirectly with **inlays** or **onlays (extracoronal)**, when a direct approach is mechanically or aesthetically inferior. Inlays and onlays are fabricated in a dental laboratory using a variety of materials including **composite resins**, **ceramics** and **cast gold alloy**s.

Indirect extracoronal prostheses

Extracoronal prostheses are defined as those **surrounding one or more natural tooth surface(s)**. The **indications** for extracoronal restorations are:

- Restoring structurally compromised teeth;
- Improving function (e.g. altering occlusal vertical dimension – OVD);
- Improving aesthetics (e.g. anterior maxillary and mandibular sextant);
- Abutments for a fixed partial denture (FPD).

Extracoronal prostheses are categorised as:

- **Inlays and onlays** – the difference between an inlay and an onlay is the extent of tooth loss requiring replacement. Broadly speaking, an inlay 'fits into', while an onlay incorporates cuspal coverage and 'fits onto' the tooth;
- **Porcelain laminate veneers (PLV)** – the principal use of PLVs is improving anterior aesthetics by altering tooth morphology and colour. PLVs are the least invasive of extracoronal restorations, usually involving the buccal surfaces of anterior teeth. If the underlying tooth colour is acceptable, only minimal tooth reduction is necessary (0.3–0.8 mm) for improving shape and colour with a thin porcelain laminate fabricated in a dental laboratory. PLVs are the most prescribed type of restoration for purely cosmetic reasons. However, it should be remembered that preparing vital healthy teeth for PLVs with little aesthetic improvement is contentious, especially if similar results are achievable with less invasive protocols such as **bleaching** or composite resin fillings;
- **Partial coverage crowns** – partial coverage crowns are an extension of PLVs. They occupy a midpoint between full coverage and the minimally invasive PLV. Many configurations are possible, e.g. ½, ¾, ⅞, etc. The rationale for partial coverage is retaining as much natural tooth substrate as possible, and hence preserving pulpal and structural integrity;
- **Full coverage crowns and fixed partial dentures (FPD) or bridges** – a full coverage, 360° crown is indicated for severely broken-down teeth, abutments for FPDs, or rarely for elective aesthetic treatment. Various materials are used for fabricating crowns depending on the clinical scenario, e.g. cast metal, metal-ceramic, all-ceramic, composite and acrylic. For vital teeth, a crown can be supported either by coronal dentine or a core build-up. For endodontically treated teeth a post-and-core complex may be necessary. Intraradicular posts are available in many materials, designs, configurations and sizes. A core can be fabricated directly in the mouth using amalgam or composite, or indirectly in a dental laboratory using cast metals or ceramics. The sole purpose of a post-and-core complex is supporting the eventual extracoronal crown. Posts and cores do not reinforce or strengthen teeth, but weaken an already compromised root and the remaining coronal dentine. A **ferrule effect** is highly desirable for cores (with or without posts);
- **Combination prostheses** – depending on the extent of the clinical requirements, any intra- and extracoronal restoration can be combined into a single entity, e.g. inlay + onlay or PLV + inlay (veneerlay).

Key points

- A direct restoration is carried out chair-side, while an indirect restoration requires using a dental laboratory.
- Black's classification, although redundant, is useful for describing the site of a lesion.
- Intracoronal restorations are surrounded by tooth surface(s).
- Extracoronal restorations surround tooth surface(s).
- Inlays are examples of intracoronal prostheses.
- Onlays, PLVs and crowns are examples of extracoronal prostheses.

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2 Overview: rehabilitation by artificial teeth

Expedient
Economical

- Average aesthetics
- Eventual bone loss at edentulous site(s)
- Possible damage to supporting adjacent teeth
- Social embarrassment
- Poor long-term retention and stability
- Poor mastication
- Altered taste sensation

Removable partial denture: tissue and tooth supported

Minimally invasive

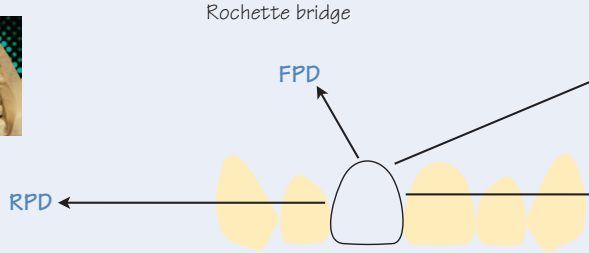
- Poor retention
- Frequent dislodgment
- Bone loss below pontic site(s)
- Technique sensitive

Fixed partial denture, e.g. Rochette bridge

Established clinical and laboratory protocols

- Irreversible destruction to abutment teeth
- Possible endodontic and/or periodontic complications of abutment teeth
- Bone loss at pontic site(s)
- Difficult oral hygiene procedures

Fixed partial denture (conventional fixed-fixed), using natural tooth abutments



Partially Edentulous

ORAL REHABILITATION

Total Edentulous

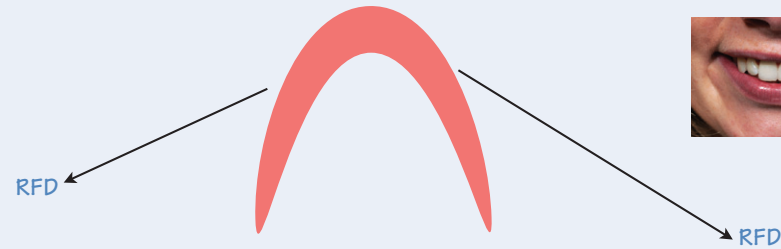
Advantages: green text

Disadvantages: red text

Supported crown

- Prevents damage to adjacent natural teeth
- Prevents bone loss at edentulous site(s)
- Restores health, function and aesthetics
- Predictable long-term success

- Protracted
- Specialist surgical training necessary for implant fixture placement
- Involves osseous and soft tissue surgical procedures
- Increased cost



Exclusively tissue-borne full denture

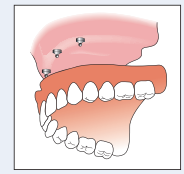
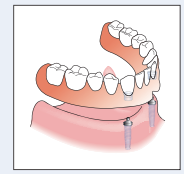
- Expedient
- Economical

- Average aesthetics
- Eventual bone loss and ridge atrophy
- Changes in facial profile
- Social embarrassment
- Poor long-term retention and stability
- Poor mastication
- Altered taste sensation

- Improved retention and stability
- Improved mastication
- Prevents bone loss at implant and retained root site(s)
- Maintenance of facial profile
- Future option for implant supported FPDs

- Average aesthetics
- Specialist surgical training and expertise necessary for implant fixture placement
- Involves osseous and soft tissue surgical procedures
- Increased cost
- Altered taste sensation

Tissue-borne combined with implants and/or root supported overdentures

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Oral rehabilitation of **missing teeth** is achieved with **removable** or **fixed prostheses**. The distinction between the two is that **removable prostheses** are supported by both soft tissues and teeth and/or implants, whereas **fixed prostheses** are exclusively supported by teeth and/or implants. Before deciding to replace missing teeth, the **shortened arch** concept should be considered.

Removable full dentures (RFD)

Edentulous rehabilitation is either with **full/full dentures**, totally supported by the alveolar ridges, or with **overdentures** supported by strategically placed implants and/or retained natural tooth roots for additional stability.

Removable partial dentures (RPD)

An **RPD** relies on support from both soft tissues and adjacent or surrounding natural teeth or implants. These dentures can be fabricated entirely from acrylic resins, or in combination with cast metal **frameworks**. **Clasp**, **rests** and **precision attachments** are often incorporated into the denture design for additional retention and stability. A variation of RPDs are **overdentures**, retained by tooth roots or **mini implants**.

Fixed partial dentures (FPD)

Before dental implants, fixed partial dentures were the state-of-the-art prostheses for replacing missing teeth, but involve gross tooth preparation of supporting abutments. More conservative FPDs, with minimal or no preparation, include **Maryland**, **Rochette** or **fibre-reinforced** bridges. While the advantages of minimal preparation are obvious, these types of bridge are less retentive, requiring frequent recementing and are often used as transitional protheses, e.g. during the surgical healing phase following bone grafting or implant placement. Other uses include **splinting** periodontally compromised mobile teeth, or as an **interim restoration** while awaiting a more permanent restoration.

Conventional FPDs require preparation of abutment teeth for supporting the final prosthesis incorporating pontic(s) for replacing missing tooth or teeth. Numerous FPD configurations are possible, e.g. **fixed-fixed**, **cantilever**, **telescopic,** with or without **precision attachments** for stress relief for long spans. FPDs have a **cast metal substructure**, which is subsequently veneered with porcelain. Newer **all-ceramic FPDs** use dense **ceramic frameworks**, e.g. of zirconia or alumina, for supporting the veneering porcelain. Although conventional FPDs using natural teeth as abutments are destructive, they still have a place in prosthodontics where local anatomy contraindicates surgery or implant placement. Besides natural tooth abutments, implants can also act as abutments for FPDs.

Dental implants

Dental implants are titanium **root forms** placed into alveolar bone. Following **osseointegration**, the implants are **prosthetically restored** with a variety of artificial prostheses including RFD, RPD and FPD. Implants are extremely versatile and used for replacing a single missing tooth, or as abutments for FPDs for replacing several missing units. In addition, implants offer many advantages compared to conventional prostheses including:

- **Improved stability** for implant supported RFDs and RPDs;
- **Preventing mechanical, periodontal and endodontic insult** of supporting teeth associated with RPDs (e.g. by clasps or occlusal rests);
- **Occlusal rehabilitation** of edentulous areas;
- **Greater bite force** compared to exclusively tissue-borne prostheses, improving masticatory performance and therefore allowing a wider choice of foods;
- **Avoiding tooth preparation of natural teeth** bounding missing spaces, e.g. for conventional FPDs, reducing possibilities of endodontic and periodontal complications;
- **Preventing further bone loss** (due to bone stimulation by the implants in edentulous areas);
- **Immunity from secondary caries** of natural tooth abutments used for conventional FPD.

Although implants offer numerous advantages compared to conventional treatment modalities, detailed planning, clinical training, experience and meticulous execution are mandatory for avoiding complications and failures. Before deciding whether the patient is a suitable candidate for dental implants, an initial **MAP** (**medical**, **anatomy**, **prognosis**) assessment is necessary:

- **Medical** considerations – age, race, gender, compromised immune system, diabetes, osteoporosis, bisphosphonate therapy, radiotherapy, psychological stress, pregnancy;
- **Anatomy** – soft tissue volume, dental biotype, bone quality and quantity, aesthetics (site: anterior or posterior regions of mouth), reduced vascularity from previous surgical traumas (e.g. apicectomies), proximity to vital structures (nerves, blood vessels, sinuses), occlusal clearance, parafunctional habits (e.g. bruxism);
- **Prognosis** – not only for an implant, but also for conventional treatment options depending on prevailing clinical situation such as:

  What is the survival rate of a tooth with periodontitis following periodontal surgery?

  What is the success of endodontic re-treatment?

  What is the longevity of an apicectomised tooth with a post crown?

A **risk assessment** is essential before deciding whether to pursue conventional treatment options, or consider implants at the outset. The cost implications of **conventional vs implant treatment** are also worth consideration. If the prognosis for conventional treatment is poor, it is futile spending time and money which could be better allocated for treatment that has greater long-term predictability.

Key points

- Missing teeth can be replaced by fixed or removable prostheses.
- Exlusively tissue bourne removable prostheses, e.g. RFD or RPD, are economical and have established protocols, but are a compromise for long-term oral rehabilitation.
- Conventional FPD are highly destructive, but obviate the need for bone and soft tissue surgical procedures.
- Implant-supported single or multiple units are the state-of-the-art treatment modality for oral rehabilitation, but require specialist training and experience for successful outcomes.

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3 Diagnostics: history taking

European Medical Risk Related History (EMRRH) questionnaire

1. Do you experience chest pain upon exertion (angina pectoris)? If so, (II).
   Are your activities restricted? (III)
   Have the complaints increased recently? (IV)
   Do you have chest pain at rest? (V)
2. Have you ever had a heart attack? If so, (II)
   Are your activities restricted? (III)
   Have you had a heart attack in the last 6 months? (IV)
3. Do you have a heart murmur, heart valve disease, or an artificial heart valve? (II)
   Have you had heart disease or vascular surgery within the last 6 months? (II)
   Have you ever had rheumatic heart disease? (III)
   Are you activities restricted? (IV) (II)
4. Do you have heart palpitations without exertion? If so, (IV)
   Are you short of breath, pale or dizzy at these times?
5. Do you suffer from heart failure? If so, (II)
   Are you short of breath when lying down? (III)
   Do you need two or more pillows at night due to shortness of breath? (IV)
6. Have you ever had high blood pressure? (II)
7. Do you have a tendency to bleed? If so, (II)
   Do you bleed more than one hour following injury or surgery? (III)
   Do you suffer from spontaneous bruising? (IV)
8. Have you ever suffered a cerebral congestion? If so, (II)
   Have you suffered from one in the last 6 months? (III)
9. Do you have epilepsy? If so, (II)
   Is your condition getting worse? (III) (IV)
   Do you continue to have attacks despite medication?
10. Do you suffer from asthma? If so, (II)
    Do you use any medication and/or inhalers? (III)
    Is your breathing difficult today? (IV)
11. Do you have other lung problems or a persistent cough? If so, (II)
    Are you short of breath after climbing 20 steps? (III)
    Are you short of breath while getting dressed? (IV)
12. Have you ever had an allergic reaction to penicillin, aspirin, latex or anything else? If so, (II)
    Did this require medical or hospital treatment? (III)
    Was it during a dental visit? (IV)
    What are you allergic to?
13. Do you have diabetes? (II)
    Are you on insulin? If so, (III)
    Is your diabetes poorly controlled at present? (IV)
14. Do you suffer from thyroid disease? If so, (II)
    Do you have an underactive thyroid? (III)
    Do you have an overactive thyroid? (IV)
15. Have you now or in the past had liver disease? (II)
16. Do you have a kidney disease? (II)
    Are you undergoing dialysis? (III)
    Have you had a kidney transplant? (IV)
17. Have you ever had cancer or leukaemia? (IV)
    Have you received drug therapy or had a bone marrow transplant for this? (III)
    Have you ever had X-ray treatment for a tumour or growth in the head or neck? (IV)
18. Do you suffer from any infections at present? (II)
    If so, which is it?
19. Do you suffer from hyperventilation? (II)
20. Have you ever fainted during dental or medical treatment? (II)
21. Do you have to take antibiotics before dental treatment? (II)
22. Are you on any medication at present? (II)
23. Women only, please: are you pregnant? (II)

The ASA rating is stated in blue parentheses, no abnormality is rated as I. The higher the number, the greater the risk of medical complication for dental treatment

Medical emergency drugs commonly found in a dental practice

Cardiac problems are the most frequent form of medical complications affecting dental treatment. A knowledge of CPR and readily available oxygen can avert fatal consequences

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History taking is the first stage before embarking on dental treatment. Recent medical advances have prolonged life expectancy, and age-related and chronic illness treated with long-term medication influences an individual's medical status. Furthermore, the ever increasing elderly population retain more of their natural teeth, requiring regular dental maintenance. Collating a patient's history is not confined to **medical anamnesis**, but also takes account of **familial medical traits** and **social habits**. All these factors can, and may, affect dental procedures.

Family medical history

There is widespread consensus among physicians that many diseases have a **genetic origin**, and a sibling may harbour genes which may or may not manifest as an eventual ailment. Also, many diseases are **multi-factorial**, and even if a given gene for a specific disease is possessed, it is not a foregone conclusion that disease will follow. For example, having a gene for cardiac problems does not mean that a myocardial infarction is inevitable. If diet, smoking and lassitude are controlled, an individual with a cardiac family history may never suffer a heart attack. The same is applicable with a family history of chronic periodontitis.

However, knowing the family medical background helps **risk assessment** and **tailoring treatment plans** unique for each patient. For example, an individual with a family history of diabetes and periodontitis will require more frequent periodontal maintenance to prevent activation of the offending gene(s) leading to periodontal destruction.

Social history

Many patients are reticent to divulge social practices since they do not perceive that this will influence their dental care. A caring and sympathetic approach is necessary, combined with detailed explanations, to obtain this information. For example, **smoking**, **drug addiction** or **alcohol abuse** affect many dental procedures and their prognosis. Another increasingly prevalent dental 'disease' is **tooth wea**r, which is non-infectious loss of tooth substrate (**erosion**, **attrition** and **abrasion**) due to lifestyle choices such as drinking effervescent acidic beverages or stress-related occlusal grinding.

Gauging the **persona** of a patient is more difficult and takes time, especially when treatment is protracted. A patient's personality, expectations and wishes may be irrelevant for simple procedures or for alleviating pain, but are decisive for certain **aesthetic** or cosmetic treatment outcomes.

Personal medical history

Medical history taking involves completing a **questionnaire**, a **medico-legal** document, which is regularly updated, reflecting the patient's changing health status. Diligent questioning is necessary to establish all medical history and medication, especially if the patient does not realise the relevance of divulging this information for dental care. The choice of medical questionnaire lies between a form bespoke for a given practice, a proprietary form purchased from dental stationers, the Medical Risk Related History (**MRRH**) or the European Medical Risk Related History (**EMRRH**) form. The bespoke and proprietary are both non-standardised questionnaires and the risk assessment is piecemeal, depending on the prevailing medical conditions. The MRRH and EMRRH forms are an attempt to standardise risk assessment, using the American Society of Anesthesiologists (**ASA**) scale for rating the severity of medical complications for easier assessment of the state of the patient's health.

Medical complications

A significant proportion of the population have medical histories or medication that affects numerous dental procedures. Furthermore, some diseases can **place the dental team at risk** of contracting illness or exposure to pathogenic organisms. The most significant systemic diseases affecting dentistry are summarised below.

- **Cardiovascular diseases** include hypertension, ischaemic cardiovascular disease (angina), myocardial infarction, congestive cardiac insufficiency, valvopathy and cardiac arrhythmias (with or without a pacemaker). A practical knowledge of cardiopulmonary resuscitation **(CPR)** is essential.
- **Allergies** can either be constitutional, e.g. asthma, or drug induced. The most common **anaphylactic** reaction is due to penicillin, but can also be precipitated by many other drugs. The symptoms are usually apparent within 15 minutes of taking the offending drug. Other allergies that may complicate dental treatment are **latex gloves**, **local anaesthesia** or dental materials, especially alloys containing **nickel**.
- **Diabetes mellitus** is not only a debilitating systemic disease, but may also increase the severity of periodontal destruction and complicate surgical or implant procedures. **Type I** diabetes is insulin dependent, while **type II** diabetes is controlled by diet. Many patients are oblivious to their condition until symptoms appear, and if detailed questioning arouses suspicion, referral to a medical practitioner for further tests is advisable.
- **Infectious diseases,** e.g. **hepatitis A, B, C**, **HIV** and **tuberculosis**, do not contraindicate dental care, but stringent cross-infection control is mandatory.
- **Epileptic** convulsions are controllable by medication in the majority of cases, but the dental surgery environment may cause stress and trigger an epileptic attack.
- **Tendency to bleed** may be due to haemophilia or anticoagulant therapy. In both situations, a medical consultant's report is essential before embarking on deep scaling or surgical procedures.
- **Drug-related complications** are secondary effects that may interfere with certain treatment; for example, antidepressants interacting with local anaesthetics, or bisphosphonate therapy causing osteonecrosis following soft tissue or implant surgery.
- **Other conditions** include pregnancy, thyroid disease, radiotherapy, kidney disease, stroke and carcinomas.

Key points

- A detailed family, social and personal medical history is essential before starting dental treatment.
- Gauging a patient's persona is helpful for aesthetic treatment outcomes.
- A standardised MRRH or EMRRH questionnaire with an ASA rating is useful for assessing severity of medical complications.
- A working knowledge of dealing with medical emergencies is essential.

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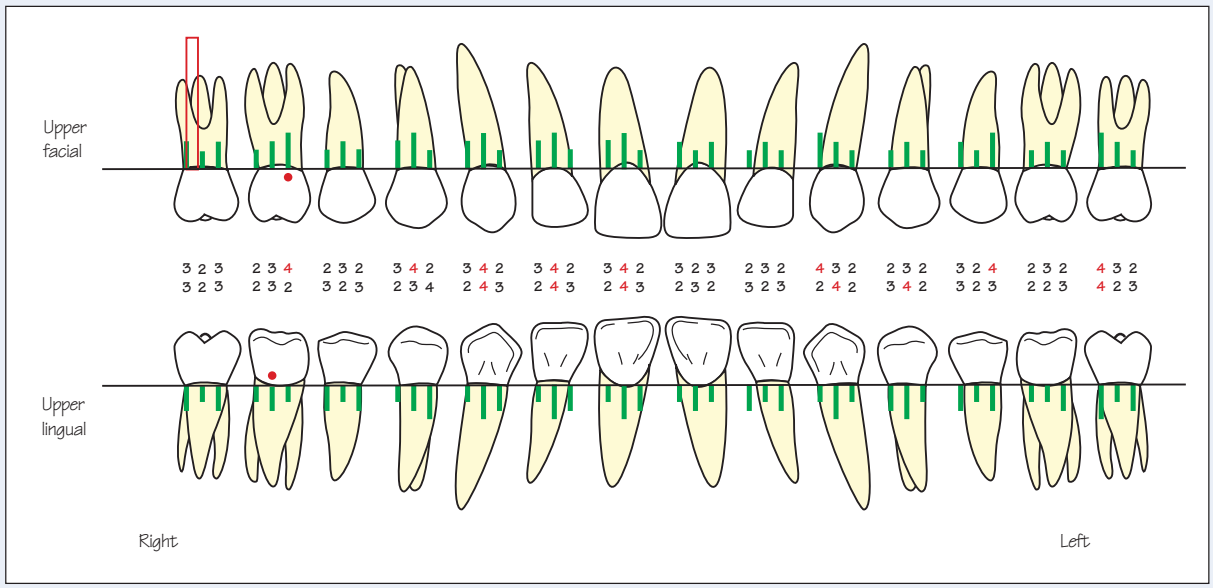
4 Diagnostics: initial consultation

Extra-oral facial assessment: frontal

Extra-oral facial assessment: profile

Photographs of the face are an excellent method for studying in detail extra-oral pathology, variations and asymmetries that affect treatment planning. For example, the parallelism of the interpupillary line with the incisal plane is essential for aesthetic approval



Computer-generated dental and periodontal charting

Dental software allows a comprehensive dental and periodontal charting, which can be readily reviewed and modified

Oral carcinoma

Early detection of cancerous and pre-cancerous lesions can be life saving

Asymmetrical gingival zeniths

Uneven gingival margins detract from 'pink' aesthetics, especially with a high lip line

Angle's Class II (ii)

Angle's Class II(ii) anterior relationship is associated with a steep anterior guidance

Tooth wear

Tooth wear is non-infectious loss of enamel and dentine, e.g. due to attrition

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The **initial consultation** is to assess the patient's current **dental status** and determine which, if any, detailed investigations or referral are necessary before arriving at a **diagnosis**.

Initial complaint

The first point to ascertain is the reason for attending, which can be **pain**, **dissatisfaction** with previous dentists, **referral**, **coercion** by family, friends and colleagues regarding poor dental health and/or appearance, **second opinion**, or a personal desire to **improve dental health** and **aesthetics**.

Dental history

Dental history taking includes the following:

- **Attitude** to oral health;
- **Regular** or **occasional** attender;
- **Dental records**, models, photographs and radiographs from previous dentist(s);
- Dental **phobias**;
- **Hobbies** or habits that affect the dentition, e.g. playing a wind instrument;
- **Sports**, **occupational hazards**, or other risky activities;
- **Persona** and expectations about dental treatment;
- **Financial** status.

Extra-oral examination

The extra-oral examination consists of a **visual** and **tactile** assessment. The **skeletal** structure, **tegumental (skin)** structure and the **musculature** are scrutinised, and deviations from the norm or pathological changes are noted.

- **Skeletal**: **facial shape** (ovoid, tapering, rectangular or square), **facial profile** (class I, II or III base), **zygomata** (prominent, receding), **angle of mandible** (prominent, receding), temporomandibular joint (**TMJ**) (deviation and/or clicking during movement, hypo- and hyperplasia of condyles) and **maxilla** (parallelism, prominent, receding, canting).
- **Tegumental**: **swellings**, **lacerations**, **bruising**, **scarring** (e.g. healing of previous disease or surgery, or result of facial cosmetic procedures), **indelible tattoos**, **suppuration**, pathological **pigmentation** and **hirsutism**, loss of **tonicity**, prominent **facial grooves** and ridges (e.g. nasolabial). Other soft tissues to consider are the shape and size of the nose, lips and chin. **Facial asymmetries** are assessed during musculature **stasis** and **contraction** (e.g. **conversing, smiling** and **laughing**).
- **Musculature**: **paralysis**, **hypertrophy** and **twitching**. In addition, **palpation** of the oral muscles is performed including **temporalis**, **masseter**, **medial** and **lateral pterygoids**. During this tactile examination, **tenderness** or **trigger points** that elicit **pain** or **spasm** are recorded. Lastly, the degree of mouth opening and **trismus** is noted.

Intra-oral examination

As well as a **visual** and **tactile** assessment, intra-oral examination is expedited by using **diagnostic adjuncts** to elucidate and confirm clinical findings (see Chapter 5).

Soft tissues

The areas to examine are the **oral mucosa**, **buccal mucosa**, **palate**, **uvula**, **floor of the mouth**, the **tongue** (especially the lateral aspects, together with **tongue thrust**), and, in children, habits such as **thumb or dummy sucking**. Any abnormality or findings are recorded, especially pathological, **cancerous** and **precancerous** lesions. Finally, impediment to **phonetics** is ascertained with sounds such as 'M', 'F', 'V', 'S' and 'TH'.

Dental charting

Nowadays, most dental charting is performed using **computer software,** which prompts the user with specific items to record, thereby avoiding omissions. The charting should include **DMF** score (decayed, missing and filled teeth), **diastemata**, **imbrications**, **tooth wear** (erosion, attrition, abrasion, abfraction), **primary caries** (in virgin teeth) and **secondary caries** (around restorations or prostheses), **direct restorations** (amalgam or composite), **indirect prostheses** (veneers, crowns, inlays, bridges), **defective margins**, **discolouration** (intrinsic and extrinsic), **fractures** (tooth, restorations or cuspal), tooth **vitality**, **removable prostheses** (acrylic, metal dentures, mouthguards, bleaching trays), **implant-supported prostheses** and **fixed** or **removable orthodontic retainers**.

Periodontal charting

Computer-aided charting also expedites periodontal charting and avoids omissions. The items to record are **halitosis**, **inflammation**, **suppuration**, **plaque** score, **calculus**, **bleeding** on probing, **pocket measurements**, location of the cemento-enamel junction (**CEJ**), **gingival recession** (class I, II, III, IV), **mobility** (class I, II, III, IV), width of **attached gingivae**, **passive eruption**, **furcation** involvement (class I, II, III), pronounced **gingival embrasures** ('black triangles'), degree of maxillary **gingival exposure** during a relaxed and exaggerated smile (norm is <3 mm), and the gingival aesthetic line (**GAL**), for assessing the maxillary anterior sextant gingival zeniths.

Occlusion

The basic occlusal examination includes **arch shape** (narrow, wide, oval, square), **Angle's classification** (class I, II(i), II(ii), III), measurement of **overjet** and **overbite**, slide from centric relation (**CR**) to centric occlusion (**CO**), lateral contacts (**canine guidance**, **group function**), **anterior guidance** (steep, normal, shallow)), **fremitus**, **occlusal interferences**, **parafunctional activity** (e.g. bruxism), **TMJ dysfunction**, **trauma from occlusion** and loss of occlusal vertical dimension (**OVD**).

Key points

- Enquire about initial complaint or reason for attending.
- Obtain dental history and dental records from previous dentists.
- Extra-oral examination assesses the facial skeleton, tegument and muscles.
- Intra-oral examination includes soft tissues, dental charting, periodontal charting and occlusal assessment.
- The initial consultation determines whether to start treatment, carry out further investigations and tests, or refer to a specialist for further advice or treatment.

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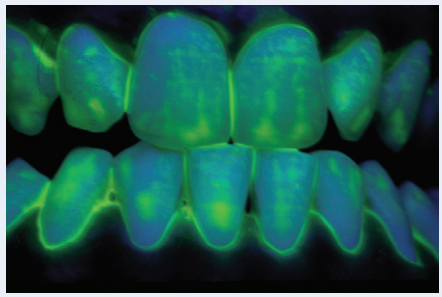
5 Diagnostic adjuncts 1

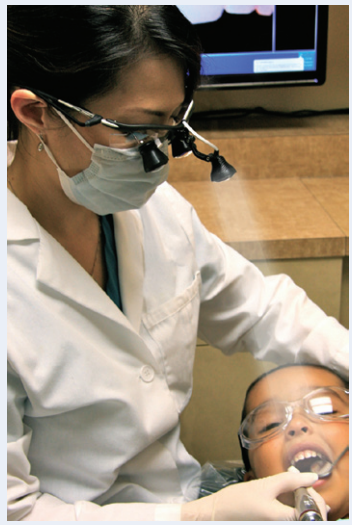
Transillumination

Useful for detecting cusp and restorative material fractures



UV illumination

Using a fluorescent disclosing agent, allows visualisation of plaque biofilm with UV light



Dental loupes

As well as choosing the magnification factor, it is important to select the correct working distance to ensure correct posture and prevent musculoskeletal strain. A fibreoptic cable can also be attached for shadow-free illumination

Operating microscope

Although the learning curve is more challenging than for loupes, a microscope offers innumerable benefits such as dual binocular vision for both the clinician and dental assistant

Traumatised teeth

Transient paraesthesia gives a false-negative result when vitality of traumatised teeth is tested using thermal or electrical stimulation

Leukoplakia

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Besides **visual** and **tactile** examination, many conditions and lesions require specific tests and adjuncts to elucidate findings and confirm diagnosis.

Illumination

The typical illumination in a dental practice is the operatory light which delivers **incident light** that is suitable for most examinations. However, other types of illumination allow visualisation of features that may be missed by traditional light sources, e.g. **transillumination** via a fibreoptic cable emphasises **fractures** (tooth and restorations), defective restorative margins and caries. In addition, **ultraviolet (UV)** illumination is useful for detecting **plaque biofilm** (with **fluorescent** disclosing solutions) or porosity in ceramic restorations.

Magnification

Visual enhancement is not limited to specific specialties such as endodontics, but is invaluable in many dental disciplines such as prosthodontics and periodontics, and in detecting lesions that may be 'invisible' to the unaided eye. Magnification **elevates visual acuity** using **loupes, intra-oral cameras**, **operating microscopes** and **projection stereomicroscopes** using 3-D video technology. Loupes offer magnification from **×2 to ×5**, while microscopes have the capability for **×20** or greater levels of reproduction.

The **advantages** of magnification are:

- Enhanced visual access to detail;
- Improved precision;
- Increased efficacy;
- Compensate for presbyopia;
- Comfortable ergonomics, avoiding musculoskeletal injuries.

The **disadvantages** of visual aids are:

- Limited field of view (beyond ×2.5);
- Reduced depth of field (with extreme magnifications >×10);
- Cross-infection concerns;
- Damage to optics (by dental debris, or air abrasion procedures);
- Learning curve (especially with microscopes).

Oral precancer and cancer lesions

Oral and oropharyngeal cancer accounts for **3%** of all malignancies, with a **50% mortality rate** for oral cancer. Early detection and management are therefore essential for increasing survival rates and minimising recurrence. The aggressiveness of **squamous cell carcinoma** depends on its **location,** which includes **vermilion border of lower lips**, **ventral surface of the tongue**, **floor of mouth**, **palate**, **buccal mucosa** and **oropharynx**.

Examples of **precancerous** lesions are **leukoplakia** (dysplasia ranging from 3% to 18%) and **erythroplakia** (high incidence of dysplasia at clinical detection). The early stages of cancer are asymptomatic, while the late stages (carcinoma in situ) show ulceration and bleeding accompanied by pain, dysphagia and lymphadenopathy. Visual inspection is insufficient for diagnosis and must be investigated with **active stains** (toluidine blue), **oral cytology** (scraping and **brush biopsy)** and **scalpel biopsy**. However, staining and scrapings may be inconclusive, and a brush biopsy is useful for lesions that do not heal in **10 days**. **Differential diagnoses** include lichen planus, frictional keratosis, leukoedema, nicotinic stomatitis, white sponge naevus, etc., where a cause cannot be elucidated. The **gold standard** for definitive diagnosis is a scalpel biopsy and histology examination.

Vitality testing methods

Methods to determine pulp vitality include **thermal**, **electrical**, drilling **cavities into dentine**, **anaesthesia**, **laser Doppler flowmetry**, **dual wavelength spectrophotometry** and **pulse oximetry**. The most commonly used are thermal and electrical stimuli that are **subjective**, while pulse oximetry is **objective**.

Thermal and electrical tests measure neural responses and are erratic and inconclusive, especially when used in children. **Heat** stimuli are **less reliable** than **cold liquids** (e.g. **1,1,1,2 tetrafluoroethane**). In addition a **false-negative** result is often obtained with **traumatised** teeth due to **transient paraesthesia** of nerve fibres. Conversely, a **false-positive** result is elicited when necrosis of the pulpal vascular tissues has occurred, leaving vital nerve fibres, which are more resilient. Both of these situations delays diagnosis and treatment of the affected tooth, often leading to root absorption.

Pulse oximetry is objective, measuring the **blood oxygen saturation** levels or circulation within the pulp. The **pulse oximeter** consists of light emitting diodes (**LED**) of two wavelengths (**red light**, **640 nm** and **infrared light**, **940 nm**) and a receptor which records the **spectral absorbance** of the oxygenated and deoxygenated haemoglobin in the tooth pulp. A computer calculates the percentage of oxygen saturation levels, which are approximately **75% to 80% for vital teeth**, compared to values at the **fingers** or **ear lobes of 98%**. The saturation levels of teeth are lower than soft tissues due to the dentine and enamel enclosing the pulp, which scatters the LED light.

Other diagnostic methods

Other methods used for diagnosis include:

- **Caries detection and periodontal assessment** (Chapter 6);
- **Radiography** (Chapter 7);
- **Computed tomography (CT)** (Chapter 8);
- **Dental photography** (Chapter 9);
- **Occlusal analysis** (Chapter 10);
- **Plaster casts and additive diagnostics** (Chapter 11).

Key points

- Transillumination is used for detecting caries, fractures and deficient restorative margins.
- Magnification facilitates diagnosis, using loupes or operating microscopes.
- Precancerous lesions such as leukoplakia and erythroplakia that do not heal in 10 days should be biopsied.
- Frequently used tests for tooth vitality include thermal, electrical and pulse oximetry.

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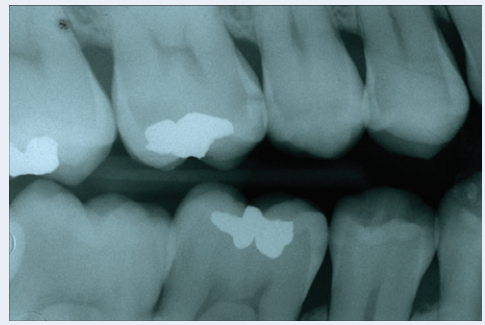
6 Diagnostic adjuncts 2

Digital score	Clinical interpretation
0 – 9	Sound enamel or early enamel lesion
10 – 17	Enamel caries
18 – 99	Dentine caries

Quantitative laser fluorescence (QLF)

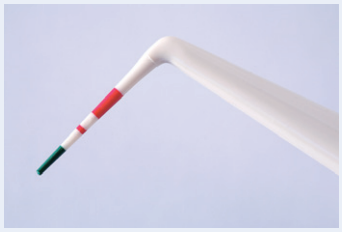
Quantitative laser fluorescence (QLF)

QLF is an objective method for detecting caries



Bitewing radiographs

Bitewing radiographs are an excellent method for detecting inter-proximal (smooth) carious lesions



Michigan-O manual perio probe

Spring-loaded probe (Click-Probe)

Florida electronic probe and digital display

Saliva assay for detecting biomarkers

Level	Process	Diagnostic tools
Clinical	Attachment and bone loss	Periodontal probing, radiographs
Tissue	Apical migration of epithelial attachment, connective tissue and bone loss	Histomorphometry, immunohistochemistry
Cellular	Presence of inflammatory cells (neutrophils), osteoclast activation	ELISA, immunohistochemistry
Molecular	Activation of receptors for endotoxins: CD-14, toll-like receptors	Polymerase chain reaction, DNA-DNA hybridisation, laser-capture microdissection

Methods of diagnosing periodontal disease

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Caries detection

Dental caries is the most prevalent lesion in the oral cavity that is diagnosed and treated in a dental practice. **Caries describes both the lesion and disease process**, and its **incidence** in industrialised countries has decreased over the last three decades. Specifically, **interproxima**l or smooth surface caries has shown a greater decline than **occlusal** lesions. Consequently, occlusal caries presents a greater challenge for early detection and treatment to prevent progression into larger cavities. Ideally, caries diagnostic tests should fulfil the following criteria:

- **Sensitivity** – ability to truly determine presence of caries;
- **Specificity** – ensure that sound tooth is registered as negative;
- **Accuracy** – number of positive and negative tests should sum to the total examined tooth surfaces.

Methods for caries **detection** include the following.

- **Histology** – remains the **gold standard** for evaluating caries, but is obviously impractical in the dental surgery. Its use is limited to research, especially of the primary dentition following exfoliation or extraction.
- **Visual inspection** – most common method for caries diagnosis, e.g. using the International Caries Detection and Assessment System (ICDAS), but is affected by operator experience and subjectivity.
- **Enhanced visual inspection** includes:
  Magnification – using loupes or operating microscope;
  Fibreoptic illumination – widely used for detecting interproximal caries, but can also be used for occlusal lesions, e.g. FOTI (fibreoptic transillumination) and DIFOTI (digital imaging fibreoptic transillumination). **Sound enamel** appears **translucent**, **enamel caries** appears **grey and opaque**, and **dentine caries** casts an **orange/brown** or **bluish** shadow;
  Enamel porosity (Ekstrand method) – assesses difference of refractive indices between air, water and enamel;
  Combination of fibreoptics and enamel porosity.
- **Electrical conductance measurements** (ECM) – measures **electrical resistance** of teeth. Intact enamel has greater resistance than carious lesions, which are porous and have a higher water content. Dentine has lower resistance than enamel, and therefore allows differentiation between enamel and dentine lesions.
- **Tactile** – explorer probes suffer from subjectivity and clinical experience, and should be used with **caution** to avoid piercing **non-cavitated** enamel (possibly reversible) **carious lesions**.
- **Bitewing radiographs** – the most popular method, especially for interproximal lesions. In addition, digital radiography allows **image manipulation** for highlighting salient lesions.
- **Caries detection dyes** – stain carious dentine, especially useful for deep caries excavation and avoiding inadvertent **pulpal exposure**.
- **Tuned aperture computed tomography (TACT)** – reconstruction of anatomical 'slice' images to form a pseudo- or true 3-D representation of a tooth, known as a **pseudohologram**.
- **Tooth staining** and **hydration** – produce erratic values.
- **Fluorescence** – either **quantitative laser fluorescence (QLF)** using a diode fluorescence device that illuminates the tooth with a pulse light of wavelength 290–450 nm or **DIAGNOdent** that uses **infra-red** light of wavelength 655 nm. The **emitted fluorescence** correlates with the extent of enamel and dentine demineralisation, e.g. a digital scale representation from 0 to 99. This is an objective assessment, but intrinsic or superficial **tooth stains** or **hypomineralisation** create variable light scattering and therefore unpredictable readings.

Periodontal assessment

The crucial factor for periodontal disease is **host genetic susceptibility**. Individuals who are susceptible to severe chronic periodontitis should be screened and identified as **genotype positive**, which helps with treatment planning and monitoring. Periodontal disease is diagnosed at the **clinical**, **tissue**, **cellular** and **molecular levels**.

The **clinical assessment** of periodontal disease is the most popular method for ascertaining **destruction caused by previous episodes** of disease, or the **effectiveness** of recent **periodontal therapy**. This includes recording bleeding on probing (**BOP**), pocket depth (**PD**) and clinical attachment level (**CAL**) using **periodontal probes** of the following types.

- **Manual**, e.g. Michigan-O or Williams. The degree of reproducibility varies with the type of probe and there are conflicting reports on whether a manual or electronic probe is more reliable. Manual probing is convenient and expedient but measurements may be erratic due to prevailing **inflammation**, presence of **plaque**, **calculus**, **over-contoured restorations**, **tooth location** and **angulation**, **patient compliance**, **probe diameter**, **angulation** and **pressure**, and **visual recording errors**.
- **Spring loaded**, e.g. Brodontic Probe (Prima, Byfleet, UK) and Click-Probe (KerrHawe SA, Switzerland). Unlike manual probes, these varieties deliver a predefined consistent force (0.2–0.5 N probe force or 255 N/cm^2 probing pressure), but are also prone to recording errors.
- **Electronic or computerised pressure-sensitive**, e.g. Florida Probe (Florida Probe Company, Gainesville, FL, USA) and Jonker Probe (Jonkers Data, Staphorst, Netherlands). These offer the advantage of delivering a constant probing pressure and electronic recording or displaying data using appropriate software. However, the probing pressure in many probes is less than **250 N/cm^2**, which is necessary to enter periodontal pockets deeper than 5 mm.

At the **tissue, cellular** and **molecular levels, biomarkers** are useful diagnostic indicators for assessing periodontal disease. Biomarkers include **microbial factors**, **host response factors** and **connective tissue breakdown products**, **bone resorption factors** (e.g. **ICTP**; type I collagen carboxyterminal telopeptide), and their levels found in **plaque biofilm**, **gingival crevicular fluid** or **saliva** are diagnostic markers for periodontal disease activity and its progression. Future developments may allow oral fluid analysis for biological markers with **chair-side assay**.

Key points

- Although dental caries incidence has declined, caries remains the most prevalent disease treated in the oral cavity.
- Subjective caries detection includes visual, tactile and enhanced visual inspection.
- Objective caries detection includes radiography and QLF.
- Periodontal probing is the most popular and convenient method for detecting, charting, and monitoring periodontal disease.

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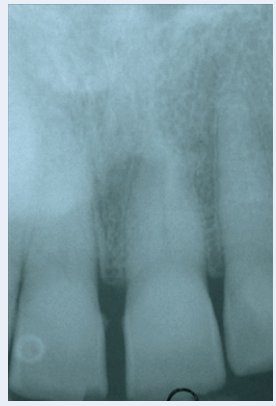
7 Radiography

Intra-oral dental X-ray equipment

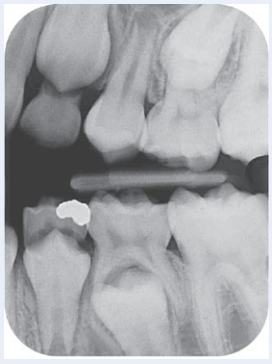
A dental X-ray unit allows the operator to select the kV, resolution, and time of exposure depending on specific requirements

Extra-oral panoramic dental X-ray equipment

Larger dental X-ray units allow extra-oral radiographs such as panoramic and lateral cephalometric images

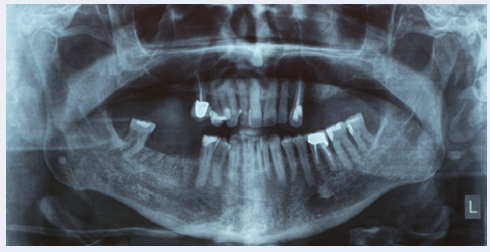


Periapical radiograph



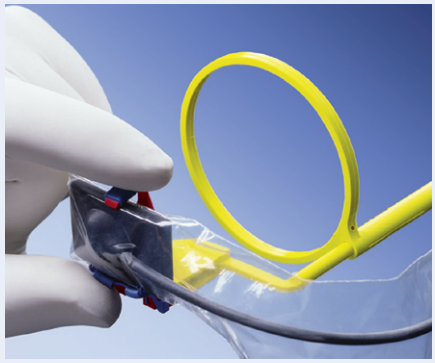
Bitewing radiograph

Lateral cephalometric radiograph

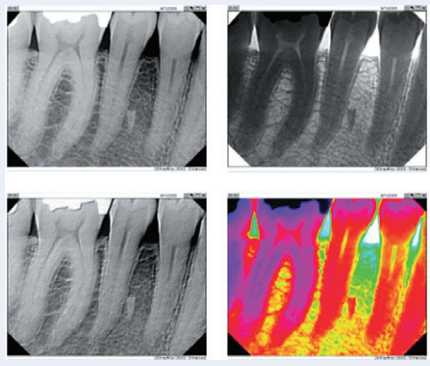


Panoramic radiograph

Radiation monitor badge



Digital CCD sensor



Manipulated dental radiograph

 Prosthodontics at a Glance, First Edition. Irfan Ahmad. © 2012 Irfan Ahmad. Published 2012 by Blackwell Publishing Ltd.

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Besides a clinical examination, **projection dental radiography** is the most frequently used diagnostic tool in dentistry. Its uses range from detecting caries to more elaborate findings such as gross pathologies of the jaws. Cone beam computed tomography (**CBCT**, discussed in Chapter 8), is the latest radiology tool, offering enhanced and sophisticated visualisation of dentomaxillofacial anatomy.

X-ray tube

The production of X-rays has changed very little since they were discovered by **Röntgen** in 1895. X-rays are produced when electrons are accelerated to strike a metal target. A contemporary dental X-ray tube for producing radiation is housed in a casing and has an appropriate sized **collimator** to restrict the emitted beam. The typical setting for intra-oral dental radiography is **60 kVp**, **7 mA**, with varying **distance** of **15–32 cm**. The **exposure time** is selected according to tooth, age and the physical build of the individual.

Radiation safety and precautions

X-rays are part of the **electromagnetic spectrum** classified as **ionising radiation,** which are potentially hazardous for living organisms, causing irreversible ailments such as cancer, sterilisation and gene mutation. The aims of radiation safety are:

- **Justification** for its use, i.e. risks vs benefit;
- **Optimisation** of protection using the lowest possible dosage, e.g. for a **periapical** exposure the limit is **2.3 mGy**;
- **Limitation** of exposure by conforming to recommended limits as specified by law. In the UK, **Ionising Radiation Medical Exposure Regulations 2000** guidelines must be observed for all types of radiographic examination.

Radiation protection is for the **operator**, **patient, ambient environment** and **third parties** (other patients and staff members in the practice). Precautions include **regular equipment testing** and maintenance, **thyroid lead aprons**, **monitoring devices/badges**, and **restricted areas** of operation.

Finally, **operator training** is essential in the taking and interpreting of radiographs, thereby avoiding the need to repeat exposures unnecessarily.

Conventional dental radiography

Film or conventional dental radiography is similar to conventional photography. A cellulose acetate sheet (film) is coated with **X-ray-sensitive chemicals** which react when exposed to radiation. Subsequently, the film is processed with chemicals (**developer** and **fixer**) to create a **black-and-white** indelible image on the cellulose acetate sheet. The processing can be performed **manually** in tanks of appropriate chemicals, or in an **automated** processing unit, which also dries the film ready for storage.

The films are available in various sizes for taking intra-oral **periapical**, **bitewing**, **occlusal**, as well as extra-oral **lateral cephalometric** or **panoramic** views. In addition, radiation dosages can be reduced by using films of varying sensitivities (**high film speeds**) or **intensifying screens** in film cassette holders (panoramic and lateral cephalometric).

The **major advantage** of film radiography is familiarity with established protocols. The **drawbacks** are a relatively higher radiation dose (compared to digital radiography), the need for visual magnification for proper analysis, environmentally toxic chemicals, and the inability to store and transmit images electronically.

The two main methods for intra-oral dental periapical radiographs are the **parallel** and **bisecting angle** techniques.

Digital dental radiography

Similar to digital photography, **digital dental radiography** has revolutionised dental radiology. The **advantages** are instantaneity, no chemical processing, reduced radiation dosage, ability to manipulate and enhance images for improved and accurate diagnosis, electronic storage, and transmission via the Internet. The **disadvantages** are the initial capital outlay for equipment purchase and training, which are rapidly offset by the innumerable benefits mentioned above.

With digital radiography, the film is substituted with a **sensor**. Currently three types of sensor are available, **CCD** (charge-coupled device), **CMOS** (complementary metal oxide semiconductor) and **SPP** (storage phosphor plate). Each type of sensor has advantages and limitations regarding altering the **exposure time**, **signal-to-noise ratio** or **image resolution**. For accurate diagnosis the resultant **image resolution** is paramount. Image resolution is determined by **spatial resolution** expressed as **pixel size**, dots per inch (**dpi**) or line pairs per millimetre (**lp mm^{-1}**). For example, a high resolution CCD sensor is 15–20 lp mm^{-1}, while an SPP system is 8 lp mm^{-1}. The required resolution depends on the diagnostic requirements, e.g. **medium resolution** is sufficient for detecting caries or gross pathology, while **high resolution** is beneficial for discriminating minute tooth or root fractures and for locating root canal anastomoses during endodontic treatment. However, high resolution images create **larger files**, requiring increased computer hard drive storage capacity, and present a challenge for transmission via email.

The process of digital radiography is as follows. After exposing the sensor to radiation from an X-ray unit, an **analogue/digital (A-D)** converter converts the analogue signal to digital data that is processed by either a **dedicated** or **generic** software for displaying as an image on a computer **monitor**. The radiograph image can be **manipulated** by altering magnification (best method for enlargement is bicubic convolution), gamma curve, density, contrast, brightness or applying filters (e.g. polarising) for emphasising or enhancing pertinent detail.

Key points

- Projection dental radiography is the commonest diagnostic tool in dentistry.
- A dental X-ray unit produces potentially hazardous ionising radiation.
- An X-ray detector can either be analogue (film) or digital (sensor).
- Radiation safety and appropriate training are paramount for preventing irreversible damage to health.
- Digital radiography offers innumerable advantages compared to X-ray films.

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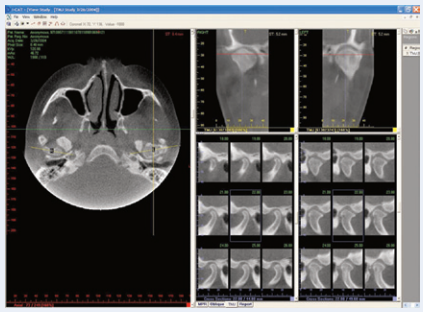
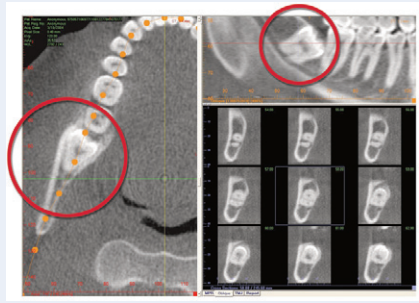
8 Computed tomography

Type of image	Effective radiation dose, E (μSv)
Full-mouth periapical examination	13 – 150
Single panoramic	3 – 11
Conventional CT of mandible	1320 – 3324
Conventional CT of maxilla	1031 – 1420
Cone beam CT	37 – 558

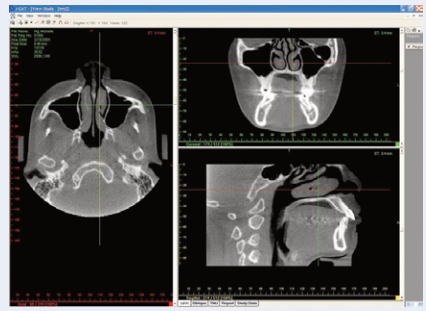
Dosimetry with different radiographic imaging methods



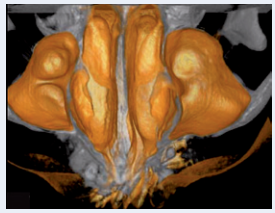
cCT axial image



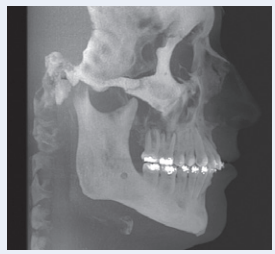
CBCT axial plane



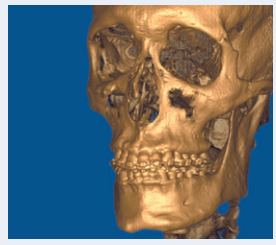
CBCT sagittal plane



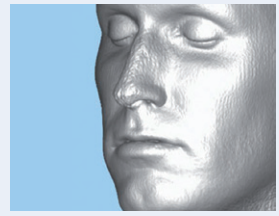
CBCT coronal plane



CBCT
Oblique planar
reformation



CBCT
Serial transplanar
reformation



CBCT
Maximum intensity
projection (MIP)

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Computed tomography (CT) is a radiology-based imaging system for evaluating skeletal structures of the body. CT imaging is one method used for scanning the maxillofacial region. However, depending on the symptoms and clinical findings, alternative methods of imaging can be considered including **digital radiography**, **magnetic resonance imaging (MRI)** and **ultrasonography** (ultrasound imaging).

Conventional CT

Conventional CT (**cCT**) imaging uses a rotating **helical fan beam** X-ray unit and detector to scan the patient's maxillofacial region. The ensuing digital slice-by-slice images, usually in the **axial plane**, are combined to create a **2-D representation**. The scan can either be a **single-slice** or **multiple detector CT** (**MDCT**), which substantially reduces the radiation dosage. CT scans are usually limited to hospitals or specialist centres due to their prohibitive cost, large size, and the requirements for periodic maintenance, training of operating staff and adherence to strict radiation controls.

Cone beam CT

Unlike the layered (or slice) images produced with cCT scans, cone beam CT (**CBCT**) scans are based on **volumetric** tomography. The 3-D cone beam X-ray source makes a 360° scan of the patient's head, which is held static with an appropriate holder. The digital information obtained is in the form of 3-D cuboid blocks known as **voxels** or **volume pixels** (similar to **pixels** in a digital camera), representing the intensity of X-ray absorption at a particular point on the image. At predefined intervals, 'basis' images are acquired (usually 300–600 per scan) and subsequently reformed with **algorithms** using computer software to yield **3-D images** in the **axia**l (and **transaxial**), **sagittal** and **coronal** orthogonal planes. This process is termed multiplanar reformation (**MPR**). As well as images in various planes, other types of possible MPR images include the following:

- **Oblique planar reformation** – 2-D non-axial images useful for assessing the temporomandibular joint (TMJ) and impacted molars;
- **Curved planar reformation –** similar to panoramic radiographs but without distortion or superimposition of the cervical spine;
- **Serial transplanar reformation** – a series of images (1 mm thick, with 1 mm separation) derived from oblique and planar reformations for assessing alveolar bone height and width, relation of nerve canals and sinuses, and shape of the condyles for determining TMJ pathologies;
- **Multiplanar volume reformation –** formed by increasing the number of voxels of a slice for 'thicker' panoramic (25–30 mm) or cephalometric (130–150 mm) images;
- **Maximum intensity projection (MIP)** – isolates the highest value voxels to form a **pseudo-3-D** structure of surface morphology. A **true 3-D** representation is also possible by adding shading effects with appropriate software to create the desired degree of 3-D. Furthermore, user interaction allows the skeletal structures to be visualised in 'real time' in any orientation from limitless angles.

Clinical applications of CBCT

The applications of CBCT are ever expanding. The technology is useful for many disciplines in dentistry such as implant site assessment, oral surgery, oral medicine, TMJ dysfunction, periodontology, endodontics, prosthodontics, orthodontics. The recent introduction of a larger, 12-inch field of view (**FOV**) enables CBCT images to substitute for conventional panoramic and cephalometric radiographs. A further application is in monitoring pathology and the efficacy of therapy.

Advantages of CBCT

CBCT technology has rapidly evolved due to the reduced cost and size of X-ray tubes, development of high-quality digital sensors, and the introduction of powerful personal computers. These factors have made CBCT equipment more **accessible**, and within reach of many practitioners as a **worthwhil**e and **affordable** investment.

As with digital photographs or radiographs, **image manipulation** is relatively easy, e.g. zoom, magnification, isolation, cropping, altering contrast and brightness, adding 'false colours' for visual enhancement of specific structures, cursor-driven measurements, image pointers (arrow, lines) and text annotations to emphasise relevant details. Another invaluable advantage is transmission of CBCT images by the **Internet** to **specialists** for **remote diagnosis**, and to **dental laboratories** for prosthetic assessment. Moreover, CBCT imaging offers numerous benefits compared to cCT scans or digital radiographs, including:

- **Collimated X-ray beam adjustment** – for altering FOV and concentrating on regions of interest (**ROI**), for example, root canal number and location within an individual tooth;
- **Image accuracy** – reduced distortion, no magnification factor;
- **Image quality** – superior due to **isotropic** voxels, less than 1 mm (compared to **anisotropic** voxels of 1–2 mm with cCT);
- **Faster scan time than cCT** – 10–70 s depending on equipment;
- **Reduced dosimetry** – compared to cCT, but higher than digital radiography;
- **Soft tissue rendering** – allows assessment of soft tissues profiles, especially useful for orthodontic therapy;
- **Fabrication of surgical stents** – exporting data to remote proprietary or dental laboratories;
- **Reduced image artefacts** – using sophisticated software.

Disadvantages of CBCT

- **Increased radiation** dosage compared to digital radiography;
- **Misuse** by inexperienced operators may cause excess dosage;
- **Radiation burden** for children, if used for periodic orthodontic monitoring;
- **Irradiation of vital organs** – pituitary gland, salivary glands, eyes, skin, bone marrow, breast, reproductive organs;
- **Training** for interpretation is mandatory for gaining maximum diagnostic value;
- **Caries detection** is unreliable;
- **Scatter** from metals, e.g. amalgam, casting alloys or gutta-percha;
- **Evolving technology** – obsolescence of equipment and software.

Key points

- cCT produces 2-D axial images with higher dosage compared to CBCT.
- CBCT is a 3-D volumetric representation with many distortion-free views.
- CBCT is becoming accessible and affordable.
- CBCT dosimetry is greater than digital radiography.
- CBCT is a rapidly evolving technology, requiring continual capital investment and intensive training.

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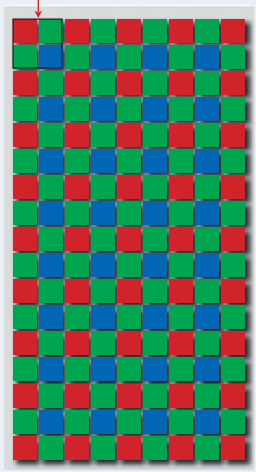
9 Dental photography

CPD

Bayer pattern

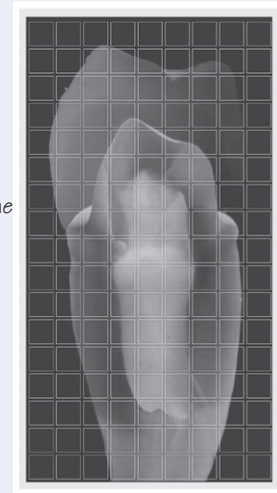
Missing inter-pixel information is interpolated from adjacent pixels

Stage 1: The object is captured by a digital sensor composed of pixels



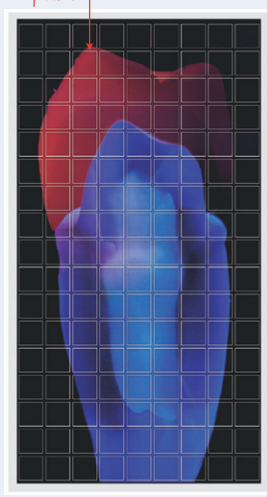
Capture

Stage 2: The analogue signal is processed by converting into digital data



Process

Stage 3: An image is displayed from the processed digital data

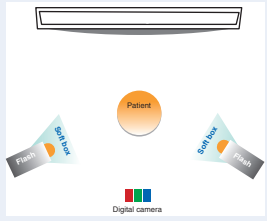


Display

SET-UPS

Camera and flashes

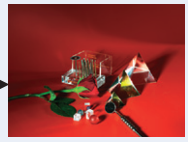
Portrait



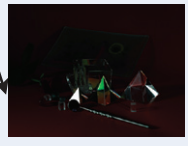
Intra-oral

Exposure: The lens aperture, or opening, controls light intensity, while the duration is controlled by the shutter speed. The aperture size is calibrated in f-stop numbers; the larger the number, the smaller the lens opening. The shutter speed is the length of time the shutter remains open when the shutter release is activated, expressed in fractions of a second, e.g. 1/125s is faster than 1/60s.

Over-exposure

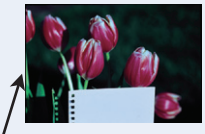


Correct exposure



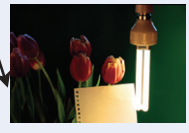
Under-exposure

White balance (WB): Setting the appropriate colour temperature to match the illumination. Photographic daylight (electronic flashes) have a colour temperature of 5500K. If the colour temperature is too high, the image will have a bluish tint. Conversely, a low colour temperature will render an image that is reddish/orange.



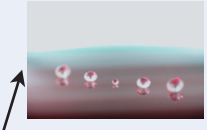
High colour temp

5500 K

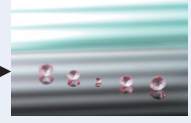


Low colour temp

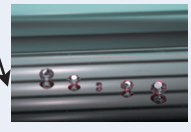
Depth of field : is the zone of in-focus objects, from front to back, or the range of distance (or objects) that are acceptably sharp within a photograph. Depth of field varies inversely with the aperture opening, i.e. a wide-open lens with an aperture of f2.8 has little depth of field; if stopped down to f22, almost everything from front to back will be sharply in focus.



F 2.8



F 5.6



F 22

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Dental photography is increasingly becoming an integral part of a modern dental practice, for improved patient care. Its uses extend far beyond documentation, e.g. during the **treatment** process (planning, progress and outcome), **education** (patient and staff), **communication** (with patients, staff, ceramists and specialists), **marketing** (practice literature and brochures) and **dento-legal** records (particularly for elective therapies such as bleaching or aesthetic/cosmetic dentistry). The digital revolution has made analogue (film) photography almost redundant, and therefore this chapter concentrates exclusively on **digital dental photography**.

Principles of digital photography

Digital photography offers the following benefits:

- **Instantaneity** and **convenience**;
- **Flexibility** (edit, crop and disseminate images);
- **Environmentally friendly** (no toxic processing chemicals);
- Long-term **economy**;
- Using **existing computers** for image display and manipulation.

The **basic principles** of digital photography can be summarised by the acronym **CPD**:

- **Capture**;
- **Processing**;
- **Display**.

The heart of a digital camera is a sensor composed of tiny, light-sensitive units called **pixels**, which replace the film emulsion of film cameras. The pixels, which can be as small as **5 µm**, are arranged in pixel squares representing the **three primary colours**, **red**, **green** and **blue** (two green pixels per square are present to match the eye's pronounced sensitivity to green light). The number of pixels on a sensor is expressed as millions of pixels or **mega-pixels**. Although most digital cameras are marketed according to the number of mega-pixels, it is important to note that the **number of pixels** represents the **image size**, **not quality**. The two most popular sensors are the **CCD** (charge-coupled device) and **CMOS** (complementary metal oxide semiconductor). Once stimulated by light entering the camera lens, the pixels produce an electrical voltage. This process of obtaining an image with a sensor is termed **image capture**.

The voltage produced by the pixels is an analogue signal, which is digitised by an **analogue/digital** (**A-D**) **converter**. The digital signal is further **processed** by software either within the camera, or by a computer using photo-editing software, e.g. **Adobe® PhotoShop®**.

After processing, the image is **displayed** on an LCD screen on the camera back, or transferred to a computer for manipulation, printing, dissemination and storage. The entire sequence of CPD is completed within a few seconds.

The photographic images can be stored on various **storage media** (computer hard drives, CD, DVD, memory sticks or cards). The choice of **file format** depends on the intended use of an image.

Some popular file formats are **RAW** (unadulterated image), **TIFF** (tagged image file format), **DNG** (digital negative graphic), **JPEG** (joint photographic experts group), **PDF** (personal document file) and **EPS** (encapsulated post script).

Equipment

The requirements of a camera for dentistry are two-fold: first for taking **portraits**; and second for **close-up** or **macro images**. Numerous cameras are available satisfying these criteria including instant **Polaroid**, **range-finders** or **digital single-lens reflex** (**DSLR**). The most versatile and appropriate choice for dental photography is the **DSLR** camera. In addition, the following are necessary for a dental photographic set-up:

- **Macro-telephoto lens** – for portraiture and close-up intra- and extra-oral images;
- **Electronic flashes** – studio flashes for full face, and compact flashes (either **ring** or **bilateral** units) for close-up intra- and extra-oral images;
- **Tripod** – for mounting camera and flashes;
- **Remote foot release** – for hands-free operation and cross-infection control;
- **Cheek retractors** – preferably the plastic variety for comfort;
- **Front-coated intra-oral mirrors**;
- **Moisture control** – saliva ejectors, cottonwool rolls and rubber dam, warm air from 6-in-1 dental syringe;
- **Cross-infection measures** – routine procedures in a dental practice, e.g. disinfection, disposable paper and plastic drapes for covering photographic equipment;
- **Patient consent** – for intended use of their pictures.

Camera settings

Most contemporary cameras are automated, requiring minimal or no user input. However, for dental photography, certain settings require attention:

- **Exposure** – combination of the lens aperture and the shutter speed. **Ideal settings** for dental photography are **f 22** to ensure sufficient **depth of field** and **1/250 s** to prevent camera shake. Using dedicated flash systems and **TTL** (through-the-lens) metering, the camera controls the duration and intensity of the flash(es) for ensuring a correctly exposed image;
- **White balance** – setting the **colour temperature** of the illumination, usually **5500 K** (Kelvin) if using electronic flash;
- **Other settings should have default levels**, e.g. contrast, brightness, colour domain, sharpness, colour space, etc. as photo-editing software can be used, if required, for image manipulation.

Dental photographic set-ups

Two basic set-ups are required, extra- and intra-oral. The **extra-oral set-ups** include:

- Full face portraits – frontal and profile views;
- Dento-facial perspective concentrating only on the lips and teeth;
- Plaster casts and dental prostheses.

The **intra-oral set-ups** are the most frequently used for photographing teeth and surrounding soft tissues, for example:

- Full arch – frontal and occlusal;
- Quadrant occlusal, lingual (or palatal) and lateral;
- Magnification views for areas of interest, e.g. a few teeth or specific regions of the oral mucosa.

Key points

- Digital photography can be summarised by CPD.
- The ideal camera for dentistry is a DSLR with ring or bilateral flashes.
- Extra-oral views include facial and dentofacial compositions.
- Intra-oral views are achieved using cheek retractors and photographic mirrors.

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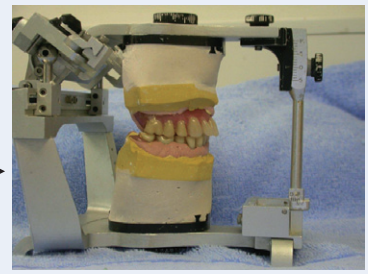
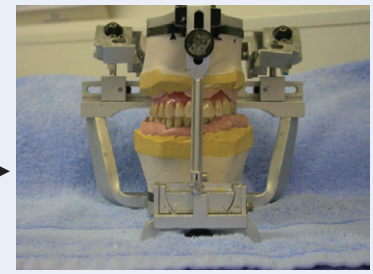
10 Occlusal analysis

Occlusal assessment consists of 3 stages: gathering occlusal data; setting up an articulator; and analysis

Plaster casts, facebow registration (shown) and articulator parameters are part of gathering occlusal data

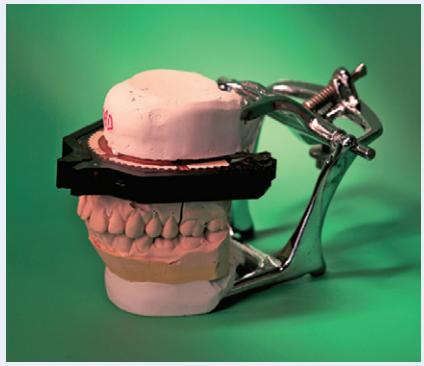


Plaster casts are mounted onto an articulator using occlusal records and necessary settings



Occlusal analysis, e.g. anterior guidance

Articulators



Hinge type

Semi-adjustable

Virtual 3-D

Occlusal analysis

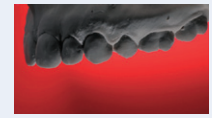
Skeletal base Class III

Cross-bite

Loss of OVD

Erratic aesthetic plane

Bruxism



Curve of Spee

Curve of Wilson

Centric occlusion (CO or MIP)

Canine guidance

Group function

Protrusion

Trauma from occlusion

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Occlusal analysis assesses **dysmorphology** and **dysocclusion** and is a prerequisite before starting prosthodontic treatment, ensuring correct function and satisfactory occlusal schemes that are essential for aesthetics and long-term harmony of the **stomatognathic system**. This chapter is an introduction to occlusion, which is further elaborated in chapters 14 to 17. It should be remembered that there are numerous **occlusal philosophies**, with varying subjectivity and bias.

Occlusal data registration

To diagnose a patient's occlusal status, and formulate a treatment plan, information needs to be transferred from the patient to an extra-oral simulating device, which can either be a **mechanical** or **virtual articulator**. Dental articulators are devices to visualise both **static** and **dynamic** occlusion. The data required depends on the chosen type of articulator and includes:

- **Plaster casts** – poured from accurate impressions of the maxillary and mandibular arches;
- **Facebow transfer** – locating the maxillary arch to the condylar hinge axis;
- **Occlusal records** – locating the mandibular cast to the maxillary cast. Check bite records, using wax or rigid addition silicone impression materials; may be required for **centric occlusion (CO)**, **centric relation (CR)** and **anterior** and **lateral excursions**;
- **Articulator parameters** – Bennett and condylar angles, intercondylar distance and spacial relationships of craniomandibular geometry;
- **Mandibular movements** – instrumental measurements using pantographs, Gothic arch tracing or computer-assisted jaw-tracking systems;
- **Articulator-related registration** – rather than transferring data from the patient to an articulator, articulator registration works the opposite way. The articulator geometry is virtually transferred to the patient, using an electronic recording system, and the articulator adjusted accordingly.
- **Digital scans** – digitising the dentition using a 3-D scanner, and subsequently outputting the data into appropriate computer software for analysis.

Mechanical articulators

Numerous types of dental articulators are available with varying complexity:

- **Hand-held or hinge –** suitable for single tooth restorations that integrate with the existing occlusal status;
- **Fixed condylar path –** similar to hinge types, for single tooth restorations and maintaining the existing occlusal status quo;
- **Semi-adjustable with fixed or average parameters (condylar and arcon types) –** suitable for most full-arch rehabilitation requiring a change of occlusal status;
- **Fully adjustable –** for complex analysis of jaw movements, occlusal equilibrium and a diagnostic aid for **temporomandibular disorders** (**TMD**), assuming there is no muscular spasm or TMJ pathology.

Virtual articulators

Presently, mechanical articulators are the most prevalent device for occlusal analysis and treatment planning. However, these devices are limited in their applications and do not represent **dynamic occlusion**. Furthermore, the influence of mobile teeth, deformation of the mandible during function, and the influence of the soft tissues and muscles cannot be simulated. Other shortcomings are **technique-sensitive methods** for **collating data,** and errors in **laboratory protocols** that contribute to decreased accuracy for representing the clinical situation.

With the sophistication of computer hardware and software, it is now possible to create a **3-D virtual articulator**. The process involves attaching ultrasound transmitters to the jaws for recording jaw motion, and scans of the maxillary and mandibular arches. The information is combined by the computer software to create a 3-D virtual articulator, which offers the following advantages:

- **Sectional slices** of individual teeth for assessing flowing and sliding contacts and interferences;
- **Protrusive** and **lateral** movement analysis;
- **Dynamic occlusion** assessment by animations of jaws in 'real time', e.g. simulated mastication;
- **Designing restorations** with correct cuspal and ridge inclines that 'fit' into a patient's occlusion;
- **Fabricating CAD/CAM restorations** by transferring data to a milling machine;
- Discovering **TMJ pathologies** during functional movements;
- **Avoiding** facebow transfer, plaster casts and measuring articulator parameters;
- **Communicating information** with patient, laboratory and specialists;
- **Plug-in modules** for orthodontics, tooth wear and holo-perspective display environment for virtual teaching via the Internet.

Occlusal analysis

A systematic occlusal analysis should consider the following items:

- **Skeletal and dental bases –** classes I, II or III;
- **Cross-bites**;
- **Occlusal vertical dimension (OVD) –** e.g. loss of vertical dimension due to tooth wear;
- **Functional and aesthetic occlusal planes**;
- **Vertical or horizontal chewing patterns** (evidence of bruxism);
- **Curve of Spee –** arrangement of teeth in the anteroposterior plane;
- **Curve of Wilson –** arrangement of teeth in the lateral plane;
- **Curve of Monson –** 3-D combination of curves of Spee and Wilson;
- **Centric occlusion (CO) –** maximum intercuspation (**MI**);
- **Centric relation (CR) –** mandible anteriorly and superiorly located in condyles (independent of tooth contact);
- **Lateral excursions – group function, canine protected (guidance)**, working and non-working (balancing) contacts;
- **Protrusive excursions –** steep or shallow anterior guidance;
- **Trauma from occlusion –** e.g. fractured fillings and/or teeth, or increased tooth mobility.

Key points

- Occlusal analysis is essential for successful treatment.
- The choice of articulator depends on complexity of the proposed treatment.
- Mechanical articulators are limited for detailed occlusal analysis.
- Virtual articulators offer promise for detailed occlusal analysis and will eventually replace mechanical devices.

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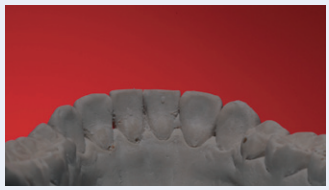
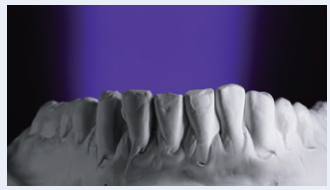
11 Plaster casts and additive diagnostics



Dental plaster casts

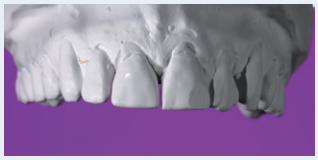
Dental plaster casts allow visualisation of the teeth from all angles



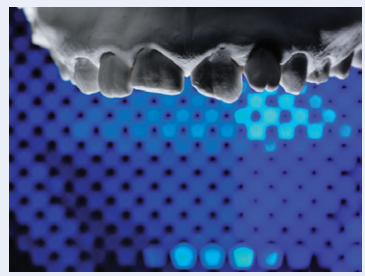
Simulations

A diagnostic wax-up is a more realistic simulation of what is clinically achievable, compared to a 2-D computer graphic manipulation

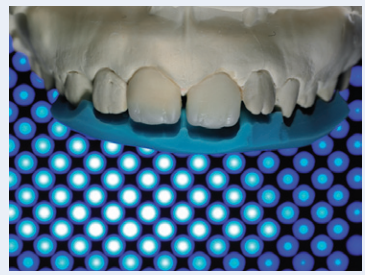
Uses of diagnostic wax-ups



Preoperative | Wax-up | Silicone index | Vacuum stents

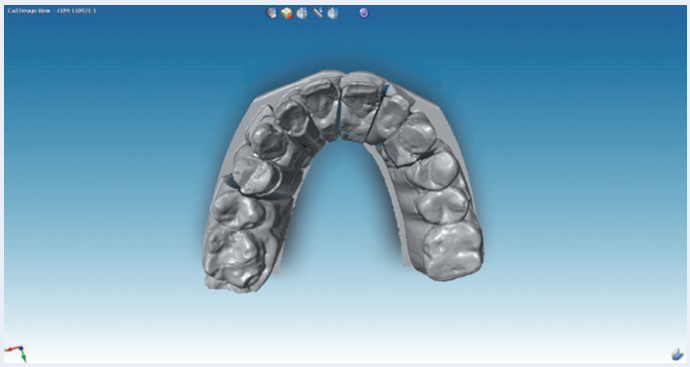


Preoperative | Wax-up | Surgical stent



Template for direct resin fillings

Digital study casts



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Dental casts, often referred to as **study models**, are pivotal for diagnosis and prosthodontic treatment planning. They provide essential information regarding tooth number, alignment and morphology as well as arch form and relation of the dentition to adjacent soft tissues and the jaws.

Dental casts

Dental casts are produced by making an impression and pouring **plaster** to recreate the dental arches and surrounding anatomy. It is customary to incorporate bases for ease of manipulation and storage.

Unmounted casts (without an articulator) serve as essential pre-treatment **documentation**. In addition, teeth can be visualised from all angles, which is usually difficult during an intra-oral examination. Hand-held pairing of the maxillary and mandibular casts permits a limited assessment of occlusion, and a thorough analysis is only possible when the casts are mounted on a **dental articulator**.

Mounted casts are an ideal method for carrying out a detailed analysis of **static occlusion**, and **dynamic occlusion** by simulating mandibular movements in various excursions. The type of articulator on which to mount the casts depends on the extent of analysis and complexity of the treatment. For most purposes, a **semi-adjustable articular** is the recommended choice.

Diagnostic wax-ups

After performing an occlusal and aesthetic analysis, treatment options can be prepared and discussed with the patient. A useful method for visualising proposed restorative prostheses is simulation in wax or composite, referred to as **additive diagnostics (wax-up** or **composite-up)**, depending on the material used. Waxes are available in various colours, and tooth-coloured varieties are ideal for anterior teeth simulations, which are useful for communicating with and educating the patient, emphasising the improvements possible with contemporary dental treatment modalities.

For aesthetic dentistry, concerned primarily with the anterior regions of the mouth, wax-ups have a major advantage over **computer simulations**. It is of course expedient to use computer software to show patients the immediate aesthetic improvements of their anterior teeth. However, the proposed 'virtual' treatment may not be clinically feasible because little information regarding arch form or occlusion is incorporated into a 2-D computer photo manipulation. On the other hand, a wax-up on mounted casts is a more realistic indication of what is clinically possible.

Diagnostic wax-ups can restore the **curves of Spee and Wilson** to their correct inclinations, to ensure a smooth and uninterrupted mandibular disclusion. A worn **incisal plane** can be restored with correct tooth proportions (**width/length ratio**) and morphology. Also, eccentric and harmful **tooth contacts** during excursions can be eliminated with correct cusp ridge inclinations. Finally, teeth can be added to or removed from the wax-up (e.g. prior to a **full arch rehabilitation**) to help discussion about various treatment options, before any irreversible procedure is carried out in the mouth.

Uses of wax-ups

Diagnostic wax-ups have many uses including:

- **Documentation** of the proposed therapy;
- **Ability to discuss different treatment options** before irreversible treatment is initiated;
- **Communication** – between patient, ceramist and specialists for **multidisciplinary** collaboration;
- **Vacuum stents** – made of transparent acrylic for intra-oral composite **mock-ups** for aesthetic approval, chair-side temporary restorations for assessing occlusal scheme changes, e.g. increasing the occlusal vertical dimension (**OVD**);
- **Silicone indices** of the wax-up for **guided tooth preparation** to ensure sufficient and precise tooth preparation and prevent inadvertent removal of tooth substrate, and retaining enamel that is crucial for adhering porcelain laminate veneers;
- **Surgical stents** – with or without cone beam computed scans (CBCT) for guided implant placement;
- **Laboratory-fabricated provisional restorations** – for resilient long-term restorations;
- **Template for definitive restorations** – copying the morphology and alignment of the wax simulation for the permanent restorations;
- **Templates for direct composite fillings** – using silicone index of a wax-up for restoring a fractured tooth (e.g. class IV cavity) with a direct composite restoration.

Digital study models and simulations

Although plaster casts are the most popular diagnostic aids for treatment planning, they are insufficient for many disciplines such as orthodontics and dental aesthetics because the dentition is unrelated to extra-oral features such as lips, eyes or the face. Furthermore, root morphology and angulation cannot be ascertained. However, with the burgeoning of CBCT technology, plaster casts will eventually be superseded by **digital study models**.

A **digital study model** is produced from CBCT data, which is processed by **algorithms** to create a 3-D representation of the teeth which can be viewed on a computer monitor. In addition, absent items such as roots, facial skeleton and soft tissue profiles can be incorporated and related to the dentition. Another benefit with **virtual diagnostic wax-ups** is obviating the need for impressions, pouring plaster models and building up with wax or composite. This allows positioning teeth correctly, by orthodontics and/or using artificial prostheses, that are harmoniously integrated with surrounding soft tissues and facial features. In addition, a **virtual occlusal analysis** is feasible**,** ensuring that the proposed restorations are compatible with surrounding and antagonist teeth. Finally, using **prototyping technologies** the data from scans can be transferred to computer-aided manufacturing (CAM) machines for fabricating conventional casts using appropriate materials such as acrylic resin.

Key points

- Dental casts of teeth are essential for diagnosis and treatment planning.
- A diagnostic wax-up is useful for proposing treatment options, and has many other uses in prosthodontics.
- Digital study models offer advantages of visualising tooth roots, facial skeleton and soft tissue profiles for enhanced diagnosis and treatment planning.

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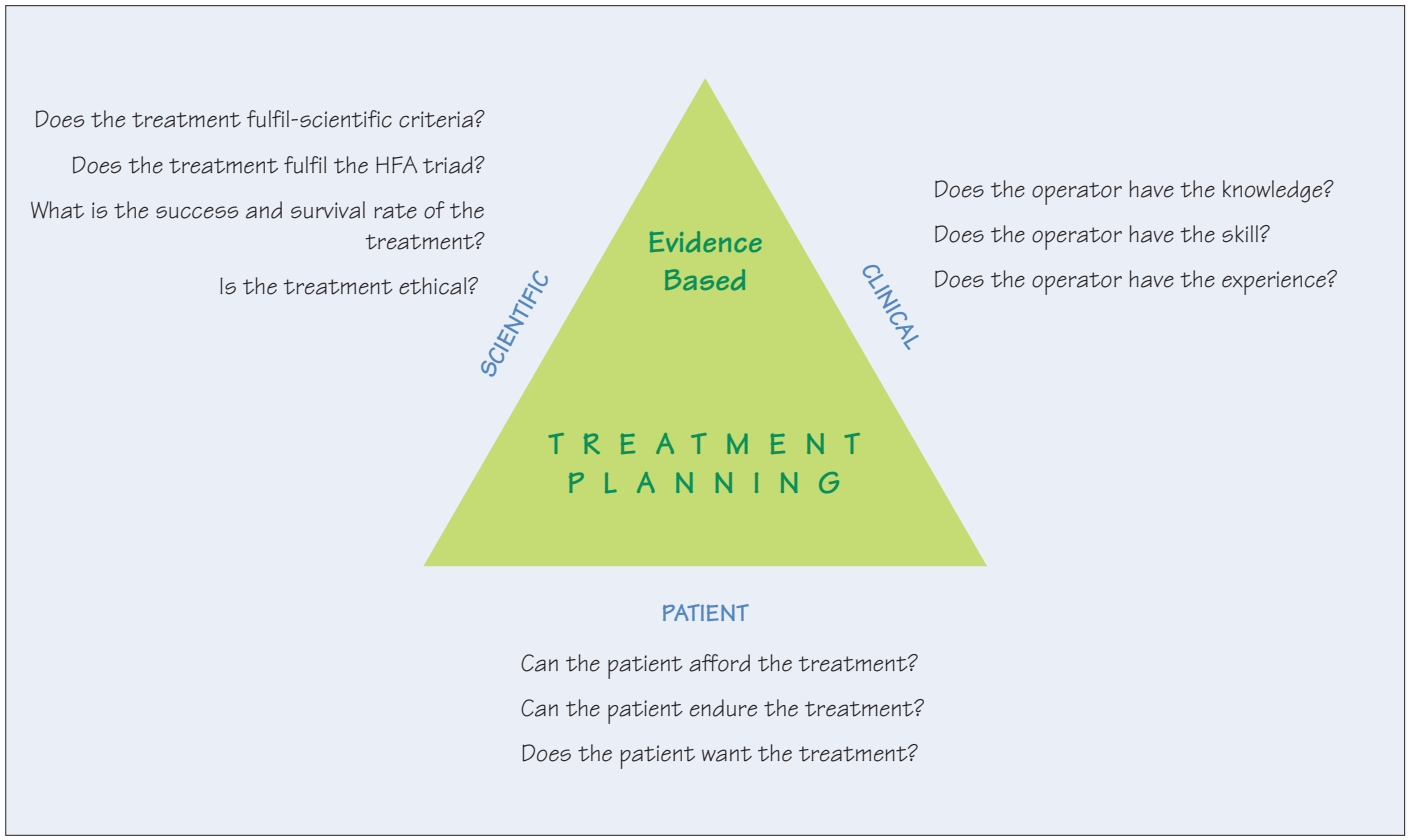
12 Treatment planning: evidence-based treatment



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After arriving at a diagnosis from the information gathered by an examination and requisite tests, the next stage is preparing treatment option(s) for therapy. Ideally, the proposed treatment should sequentially restore **health**, **function** and **aesthetic** (the **HFA triad**). The HFA triad is a **sequence**, where **health is the primary goal**, followed by **function** and **aesthetics**. Therefore, if conditions are not optimal, achieving health is the priority, at the sacrifice of function and aesthetics. However, in reality, achieving this Utopian goal is challenging and often a compromise may be the best possible outcome. It is essential to recognise and communicate compromises to the patient at the onset of treatment, rather than when complications arise.

Evidence-based (**EB**) treatment planning is not only a sound scientific model, but also a systematic approach to decision-making. EB treatment consists of three elements:

- **Scientific credence**;
- **Clinical erudition**;
- **Patients' needs and wants**.

Scientific credence

Before considering a specific treatment option, it is important to arrive at a **definitive diagnosis**. If the diagnosis is incorrect, the therapeutic options will also be incorrect. In some circumstances, there may be more than one treatment option, and each choice should be assessed to ensure there is sufficient research and clinical trials evidence to support its long-term efficacy.

Besides scientific validity, the patient should be informed of the likely survival or success rate of each treatment option. **Survival** and **success rates** are not synonymous. **Survival** implies that a restoration of prostheses has endured, but may be functionally and aesthetically inadequate. For example, a crown with defective margins causing periodontal inflammation together with tooth mobility is neither aesthetic nor functional. Conversely, **success** implies that a treatment option has not only endured, but is also fulfilling all the intended requirements.

The next item to consider is **ethics**, which comprises:

- **Nonmalfeasance** – 'doing no harm' (the Hippocratic principle);
- **Beneficence** – well-being of patients;
- **Autonomy** – veracity in clinician–patient relationships;
- **Justice** – fairness.

At times the clinician is faced with the dichotomy of clinical necessity and the patient's desires for a particular treatment. This scenario is frequently apparent when a patient requests **elective aesthetic (or cosmetic) treatment**. Ultimately, the decision to provide or refuse treatment resides with the clinician. However, when marketing and actively promoting cosmetic dentistry, it is worth remembering that there is a fine line between **persuasion** and **coercion**.

Clinical erudition

The second part of EB treatment planning is **operator factors** (both **clinician** and **ceramist**, if using a dental laboratory).

The first aspect to consider under this heading is **knowledge**. Knowledge is acquired, not innate or possessed. To learn any technique or procedure requires a certain degree of knowledge to perform a given task. As well as undergraduate education, postgraduate training is essential for gaining insight of a particular discipline. Attending conferences, reading journals and participating in hands-on courses is mandatory to keep abreast of recent scientific research and updates on new techniques.

Besides attaining knowledge, it is essential to possess the **skill** and manual dexterity to perform a procedure. Knowledge alone is insufficient for clinical practice. Furthermore, **clinical self-deprecation** is paramount for delivering successful treatment. If the proposed treatment plan is beyond one's capabilities, it best to refer to a specialist at the beginning, before embarking on procedures that may end in failure. Referral as a last resort is not only embarrassing, but can result in justified litigation.

Having gained knowledge and skills does not automatically equate to success. In addition, **experience** is prerequisite for ensuring **predictability**. Experience is the result of making and learning from mistakes. It is an entity that develops over time and as a result of repetition. Experience is also important for making judgements regarding specific treatment options. A protocol or material that works for one clinician may be a disaster for another.

Patients' needs and wants

Often, an elaborate treatment is rejected by the patient, not because it is scientifically unsound or from lack of trust or confidence in the practitioner, but because of **financial constraints**. However, offering alternative treatment options that achieve only health may be at a fraction of the cost compared to a treatment plan that ideally achieves function and aesthetics. Sometimes a compromise is the only option that a patient can afford.

Another reason for rejecting treatment is a **protracted** treatment plan spanning several months or years. This is especially true for medically compromised or infirm elderly patients. **Dental phobias** or simply **indifference** to oral health are other reasons for reluctance to accept dental treatment, and counselling and educating is the ideal way forward.

Finally, **aesthetic dentistry** is a unique clinical situation. As opposed to other forms of treatment modalities, the success of aesthetic or cosmetic dentistry involves **patient participation**. Even if all clinical procedures are executed meticulously, adhering to sound scientific principles, the patient may judge the treatment outcome a failure. Dental aesthetics is fraught with **subjectivity**, and it is imperative to understand the patient's desires before starting therapy. It is also important to clarify and discuss foreseeable compromises, because failure to do so will inevitably be costly and disappointing.

Key points

- EB treatment planning avoids a haphazard approach at the treatment planning stage.
- EB treatment has three constituents: scientific credence, clinical erudition and patient needs and wants.
- It is advisable to inform patients of compromises before starting treatment, especially that involving aesthetic or cosmetic dentistry.

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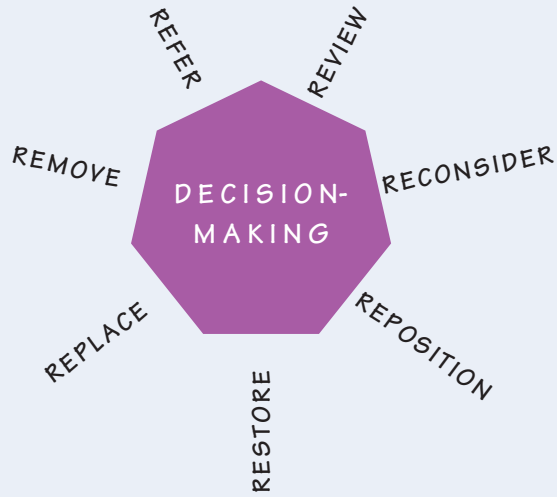
13 Treatment planning: decision-making



Review caries

Caries presenting as hard lesions can be left in situ and monitored

It may be possible to leave caries-infected soft dentine, if a peripheral enamel/filling seal is achievable

SDA

Assuming health can be restored to 10 anterior occluding teeth (SDA concept) the molars do not need replacing for oral health and comfort

If the lower canines and premolars can be replaced (e.g. with implants), the mandibular molars do not need to be replaced for the SDA concept

Reposition teeth to...

Create space for prosthetic unit

Close diastema

Create space for restorations by intrusion

Upright roots to create space for implants

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Decision-making is crucial at the **treatment planning** stage. When presented with oral disease (of the hard or soft tissues), the options available are:

- **Review** – e.g. caries or periodontal disease;
- **Reconsider** – e.g. retain edentulous spaces (**shortened dental arch** concept);
- **Reposition** – orthodontic appliances for realignment, closing or gaining space;
- **Restore** – with direct or indirect restorations, root canal therapy, etc.;
- **Replace** – replace existing restorations, or close edentulous space(s) with removable, fixed or implant-supported prostheses;
- **Remove** – extract, with or without bone and soft tissue grafting;
- **Refer** – to specialist for advice or treatment.

Very often, a combination of the above is indicated to arrive at a treatment plan with a **multidisciplinary** approach. Many of the options listed above are discussed in subsequent chapters. This chapter concentrates on a few issues that should be addressed during the planning process.

Review (monitor) caries

Traditional teaching is dogmatic about removing all carious lesions, whether they present as hard or soft enamel/dentine lesions. However, research has shown that **hard lesions** can be left in situ and monitored for progression before considering a filling. For example, non-cavitated occlusal caries can either be fissure sealed, or periodically coated with chlorhexidine/fluoride varnish to arrest the lesion or allow remineralisation.

Similarly, a shift in attitude is beginning to emerge regarding caries that presents as **soft dentine lesions**. The **conventional approach** is that caries-infested **soft dentine** be 'completely' removed until sound or **hard dentine** is reached, and restored with a suitable filling. The **new approach** is that infected soft dentine can be left, and the cavity restored with a filling. The **rationale** for this is that it is impossible to remove all bacteria from a lesion, and attempting to do so may result in pulpal exposure. So long as the cavity margins have intact enamel (decay-free and not hypocalcified), a hermetic margin seal with a dentine bonding agent and a composite resin filling will deprive any remaining bacteria of nutrients and retard their proliferation. This allows time for formation of a secondary dentine barrier to protect the dental pulp. Although considered heretical by some at present, further research may confirm the validity of this protocol.

Shortened dental arch (SDA)

Contrary to popular belief, it is not always necessary to restore a partially edentulous dentition to a full complement of teeth, the so-called **'28-tooth syndrome'**. The **SDA concept**, although not without its critics, states that **10 occluding pairs of teeth** (six anterior teeth and usually the four premolars), are sufficient to ensure oral aesthetics and function. Both **cross-sectional** and **longitudinal studies** have concluded that the SDA concept is within the **adaptive capacity** of the stomatognathic system, with little variability (compared to a full dentition) in **masticatory ability**, signs of **TMD**, **tooth migration**, **periodontal disease** and general **oral comfort**. The ethos of the SDA is that efforts should be directed at **saving and maintaining the incisors, canines and premolars** at the expense of the molars. Also, providing removable dentures for **bilateral free-end saddle** to restore occlusal function may introduce **iatrogenic insult,** e.g. root caries. Furthermore, restoring **missing molars** with **implants** may be **clinically superfluous** and **scientifically unsound**.

However, to adopt the SDA concept, certain criteria are essential:

- **Aesthetic and functional** demands are satisfied;
- The remaining teeth are **periodontally sound**;
- Absence of pathological **tooth surface loss (wear)**;
- No pre-existing **TMD symptoms**;
- No **anterior open bite**, **class III** or deep **class II** malocclusions;
- The clinical situation should be **monitored** and regularly reviewed so that the above criteria are maintained.

Reposition

In some instances repositioning teeth to a favourable position may be all that is required for achieving aesthetic and functional objectives, and will minimise irreversible restorative procedures. Orthodontics movement(s) can be used to **realign** teeth and roots, **close diastemata**, **create space** for prosthetic units, reduce **open** and **deep overbites** (levelling the curve of Spee), rectify dental **cross-bites**, **expand arches** and relieve **crowding**. The basic **movements** include **tipping**, **rotation, translation, root torquing, extrusion, intrusion and arch expansion**.

The **drawbacks** of orthodontics are **protracted** treatment times, **poor patient compliance**, **root absorption** and indefinite **retention** following therapy.

The choice of orthodontic appliance depends on the complexity of treatment and the type of desired movement. Orthodontic appliances are categorised as follows:

- **Removable** – full-arch acrylic appliances with wires, brackets, screws and springs. Ideal for tipping movements, intrusion/extrusion (**Dahl appliance**), arch expansion, but limited for complex positioning or root torquing;
- **Fixed** – wires, springs, elastic bands, etc. held with steel or plastic brackets bonded onto **labial** or **lingual** surfaces of teeth. These varieties of appliance are state-of-the-art for the majority of tooth movements;
- **Clear aligners** – full-arch acrylic appliances generated from a computer virtual diagnostic set-up. Using software simulation, the teeth are positioned to an ideal position, and a **series of clear aligners** constructed on computer-generated models. As tooth movement progresses, the successive appliance in the series is worn until treatment is complete. A wide range of movements are possible, especially in combination with fixed appliances. The use of clear aligners is relatively new, introduced in 1999; future developments in this emerging technology may allow more complex movements.

Key points

- Decision-making is summarised as review, reconsider, reposition, restore, replace, remove or refer.
- Recent paradigm shifts should be considered and incorporated into treatment planning options, e.g. removal of caries, SDA concept and repositioning teeth.

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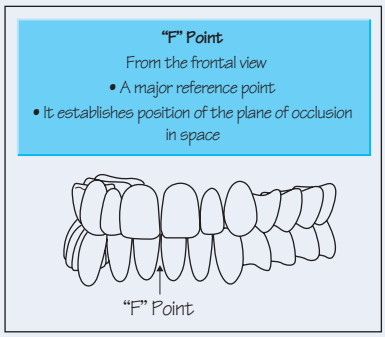
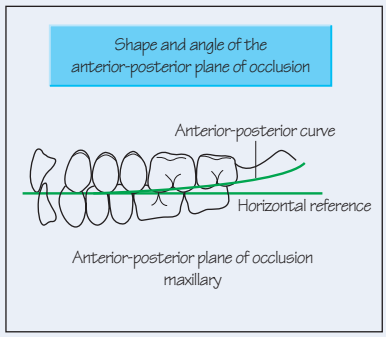
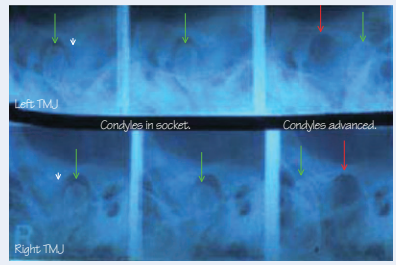
14 Occlusion: terminology and definitions





Centric occlusion (CO)

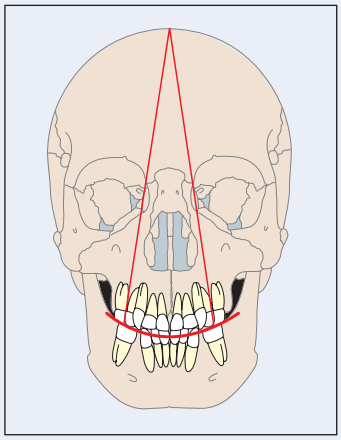
A position of the mandible when there is maximum intercuspation of the maxillary and mandibular teeth



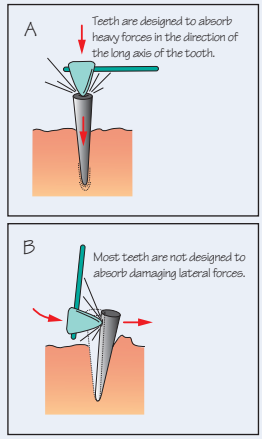
Transcranial radiograph of TMJ. Green arrows: Head of condyle. White arrows: Articular tubercle. Red arrows: Glenoid fossa.

Centric relation (CR)

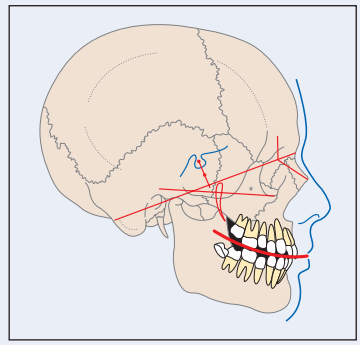
A position of the mandible dictated by the shape of the TMJ and the mandibular condyles. This is the only reproducible position of the mandible and is used for complex occlusal rehabilitation



Curves of Wilson

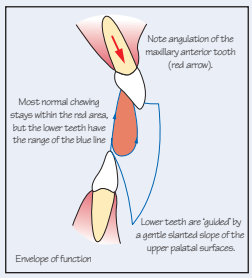


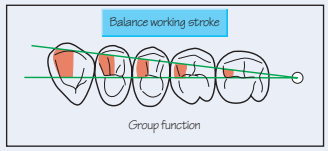
Axial and non-axial forces



Curves of Spee

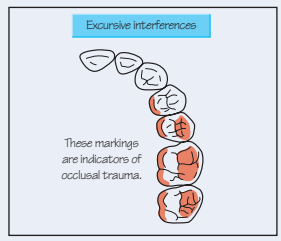
Axial forces directed through the long axes of teeth are better managed by the stomatognathic system than non-axial (lateral or oblique) forces

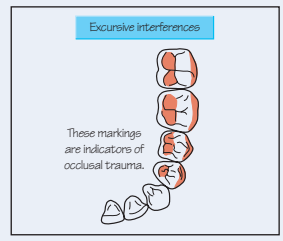




Guidance

Anterior guidance involves the incisors (within envelope of function), while lateral guidance can be either by the canines alone (canine guidance), or a combination of posterior teeth (group function)





Interferences

A non-working side interference may cause cross-arch pivot opening of the working side. The initial tooth contact in CR should be eliminated if the tooth is to be restored

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There are few topics in dentistry that are more shrouded in mystery than the subject of occlusion. The major reason is that our knowledge and understanding of occlusion is incomplete. There has been much speculation and various theories have been put forward, but opinion remains fragmented. However, there are basic principles that are undisputed, and this chapter covers these points, offering a practical approach for prosthodontic treatment.

Curves of Spee, Wilson and Monson

Viewed from the lateral aspect, i.e. the sagittal plane, the **curve of Spee** is defined as an anteroposterior curve touching the incisal edges and cusps of the dentition and passing through the mandibular condyle. The curve of Spee was originally proposed with a **radius of 2.5 inches**. A similar curve exits in the bucco-lingual plane, termed the **curve of Wilson**. The **curve of Monson** is a 3-D representation of the curves of Spee and Wilson, depicted by a sphere with a **radius of 4 inches** contacting all incisal edges and cusps of the mandibular and maxillary teeth. The significance of these curves is that, in an unworn dentition, the anteroposterior and bucco-lingual curvature allows **unimpeded mandibular lateral and protrusive excursions**. However, disruption of these curves due to tooth wear, migration or tooth loss causes occlusal disharmonies, which require addressing to re-establish these curves.

Centric occlusion

Centric occlusion (CO) is apparent when antagonist teeth are in a position of maximum intercuspation position (**MIP**). CO is influenced by **tooth shape** as well as **neuromuscular 'memory'**. In CO, the occlusal forces are in an ideal **vertical direction**, directed through the **long axis of the teeth** and subsequently dissipated by the periodontal ligament and alveolar bone. In the majority of circumstances, most restorations are tailored to 'fit' this occlusal status quo.

Centric relation

Centric relation (CR) is when the mandibular condyles are maximally seated in their fossae (**hinge axis position**). This is an anatomically determined position, not influenced by the dentition. At this position there is usually **initial tooth contact**, and then a lateral or anterior **slide to CO**. In the minority of the population (10%), CR and CO are coincident, without any slide (or deflective contacts) from CR to CO.

Without clinical symptoms, a slide from **CR to CO is not detrimental** to health, and occlusal adjustments to eliminate defective contacts are unjustified. The relevance of CR is important in the following situations:

- When the tooth to be restored is the **initial contact at CR**;
- If anterior teeth require restoration and there is a substantial shift in CR against the teeth that require artificial restorations;
- If occlusion is to be altered, e.g. when a **new occlusal vertical dimension** (OVD) is planned;
- **Establishing a new OVD** following tooth wear. Tooth wear is accompanied by **alveolar compensation**, leaving insufficient interocclusal space to accommodate restorative materials to restore the incisors. Two methods are available to create interocclusal clearance. The first is to reposition the mandible in CR using an **anterior deprogrammer** (assuming there is a horizontal shift from CR to CO). The rationale for this is that tooth wear causes the mandible to reposition itself in an anterior and superior direction. An anterior deprogrammer, e.g. **Lucia jig**, helps relocate the mandible to its original CR position, i.e. posterior and inferior directions, and thereby creating interocclusal clearance for the restorative materials. The second method is using a **Dahl orthodontic appliance,** allowing **periodontal overeruption** of the posterior teeth and **intrusion** of the anterior teeth.

Guidance

During excursions, the mandible is guided by the teeth. In theory, any teeth can guide the mandible. The forces generated in excursions are **oblique** and not along the long axis of a tooth. Hence, these **lateral forces (non-axial loading)** are more detrimental than the vertical forces observed in CO, a point worth remembering when restoring guiding teeth with artificial restorations. **Mutual protection** is when the posterior teeth contact in CO to **protect the anterior teeth**, and the anterior teeth and canines disclose the mandible in protrusion and lateral excursions, respectively, to **protect the posterior teeth**.

In **protrusion**, the **incisors** act as the guiding teeth. The so-called **anterior guidance** can be **steep** or **shallow** depending on the degree of overbite. This is significant when choosing restorative materials for restoring anterior teeth, i.e. a steep anterior guidance places greater stress on an artificial material, requiring a more resilient restoration, e.g. metal as opposed to all-ceramic. The **posterior guidance** of the mandible is limited by the shape of the temporomandibular joints (**TMJ**).

In **lateral excursions** the guiding teeth are the canines in isolation (**canine protected or canine guidance**), or the canines in combination with other teeth, usually the premolars (**group function**). Group function allows **lateral forces** to be distributed among several teeth, placing less demand on the restorative material.

Interferences

Any contact that impedes mandibular excursions or reaching CO is termed an **interference**. A **working side interference** is on the side to which the mandible is moving, while a **non-working side interference** is on the opposite side. **Most interferences are insignificant**, since the stomatognathic system adapts or deliberately avoids them during function. However, **interferences become relevant when considering prosthodontic treatmen**t. For example, a non-working side contact may cause **cross-arch pivot**, lifting the teeth on the working side. Ideally, **non-working side interference should be eliminated before starting tooth restorative treatment**, while **new interferences should not be introduced by the artificial prostheses**.

Key points

- The items to consider are curves of Spee, Wilson and Monson, CO, CR, guidance and interferences.
- There is no justification for indiscriminate pursuit of occlusal equilibrium in order to achieve an 'ideal occlusal scheme'.
- Occlusal adjustments before prosthodontic therapy are justified in order to avoid compromising new artificial prostheses.

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15 Occlusion: clinical procedures

Shimstock foil (8 µm)

Coloured articulation papers (40 µm)

Photographic documentation

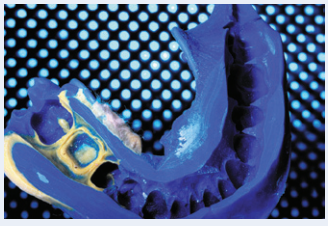
Study casts

A visual and tactile examination requires the above items

OCCLUSAL INSPECTION

A detailed occlusal analysis requires the items below

Accurate impressions



Occlusal record in CO, CR, protrusive and lateral

Articulator (semi-adjustable)

Facebow transfer

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Even if an **occlusal status quo** is envisaged, a preoperative occlusal assessment is worthwhile. Furthermore, it is instructive to know the patient's occlusal status so that the treatment provided does not disturb the **existing occlusal equilibrium**. This chapter describes the salient clinical procedures of an **occlusal examination**.

Centric occlusion

To observe **centric occlusion (CO)**, the patient is asked to bite on their posterior teeth, so that **maximum intercuspation position (MIP)** is achieved. In this position there should be maximum contact between opposing teeth, which is dependent on **tooth shape** and **neuromuscular 'memory'**.

Centric relation

Centric relation (CR) is a **predictably reproducible anatomical position**. In order to place the mandible in **CR**, a **transient neuromuscular amnesia** is necessary so that the mandible can be freely guided into its most posterior and superior location, rather than its habitual CO. **Methods** to place the mandible in CR include:

- **Bimanual mandibular manipulation**;
- **Anterior deprogramming with a jig**;
- **Gothic arch tracing**.

Visual and tactile inspection

A **visual examination** requires the following armamentarium: **photographic documentation**, **Shimstock foil**, **articulation paper** and **study casts** to view the teeth from the lingual perspective.

Placing the mandible in **CR** allows the **initial tooth contact** to be observed, and subsequent slide (if any) into **CO**. Articulation paper of one colour is used to mark tooth contact in CO. Another paper of a different colour is used to **superimpose contacts** during various **mandibular excursions**. This allows clear distinction between CO and guiding contacts, as well as discriminating eccentric contacts or interferences. The **supporting cusps** in both arches are verified, i.e. **palatal cusps of maxillary teeth** and **buccal cusps of mandibular teeth**. The visual inspection should also detect **degree of mandibular movement**, **trismus**, **wear facets** and **shifts** and **clicking** of the **TMJs** (temporomandibular joints). Finally, the **curvature of the occlusal planes** is noted, and whether these conform to the curves of Spee, Wilson and Monson.

Tactile examination includes palpation of the major **muscles of mastication**, i.e. **masseter**, **temporalis**, and **medial and lateral pterygoids**. The **TMJs** are also palpated for tenderness or eliciting a painful response, especially if the patient reports a history of temporomandibular disorders (**TMD**). Differential diagnosis of TMD includes symptoms arising from **bruxism**, of **myogenous** or **articular** origin. Palpation is also useful for ascertaining the degree of **tooth mobility** and **fremitus** during mandibular movements.

Impressions

Accurate and precise **full arch** impressions and subsequent mounted plaster casts are essential for extra-oral visual inspection. It is recommended that **addition silicone impression materials are used** rather than alginates, which have poor dimensional stability and distort if there is a prolonged delay in pouring the models.

Occlusal records

It is important to decide at which occlusal vertical dimension (**OVD**) the casts are to be mounted, irrespective of whether they are mounted in CO or CR. Usually, the casts are mounted to the OVD at which the patient is to be restored. If **CO is obvious**, and the treatment relatively simple, occlusal records are superfluous, since they may prevent accurate location of the opposing model. If **CO is not obvious**, the casts must be mounted in CR at the chosen OVD.

Many materials are available for recording occlusal positions, e.g. **wax**, **acrylic**, **zinc-oxide eugenol** or **addition silicone** bite registration formulations. It is advisable to use similar materials for impressions and occlusal records, since differences in material accuracies may prevent accurate location of the bite records onto the plaster casts.

Articulators

The **choice of articulator** is determined by the complexity of treatment (see Chapter 10). If an articulator is required, the most widely used is a **semi-adjustable articulator**, **with average articulator parameters**, i.e. Bennett and condylar angles, intercondylar distance and spacial relationships of craniomandibular geometry are pre-set to average values. Although not a true representation of the clinical situation, this device is satisfactory for the majority of prosthodontic treatment.

If a **fully adjustable** articulator or **articulator-related registration devices** are chosen, further parameters are required, and greater adjustment possible, e.g. **intercondylar distance**, **condylar and Bennett angles, upper and lower rear wall inclinations and fossae morphology**.

Facebow transfer

A facebow transfers the orientation of the maxillary arch relative to the condylar hinge axis. The facebow can be either an **earbow** or a **kinematic** type, depending on the chosen articulator device. The basic elements of a facebow are:

- **Bite fork** to register the cusp tips and incisal edges of the maxillary teeth;
- **Two posterior reference points,** e.g. **external auditory meati** for **orientation** of the **transverse condylar axis**. If the right and left **external auditory meati vary in height**, it is better to align the facebow (earbow type) so that its horizontal plane **coincides with the interpupillary** line to avoid canting of the maxillary cast when mounted onto the articulator;
- **One anterior reference point,** e.g. the **ala-tragus line** or an **arbitrary point** 43 mm superior to the maxillary lateral incisor.

Key points

- An occlusal inspection can be limited to visual, tactile and study casts, or involve mounting casts onto an articulator.
- Items necessary for mounting casts are full arch impressions of both arches, occlusal records and a facebow transfer.
- For the majority of prosthodontic treatments, a semi-adjustable articulator with pre-set average values is adequate.

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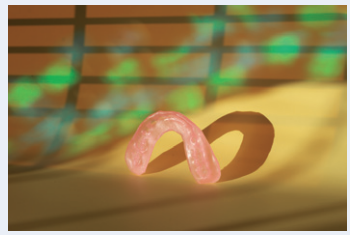
16 Occlusion: laboratory procedures

Impressions

Facebow registration



Occlusal record

Photographs

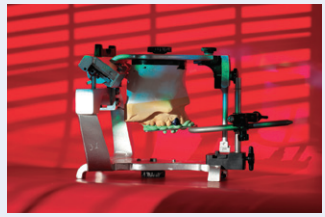
Clinical items necessary for mounting casts and setting dental articulator parameters

LABORATORY PROCEDURES

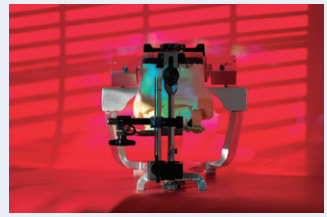
Occlusal analysis and uses of articulator-mounted casts

Plaster casts

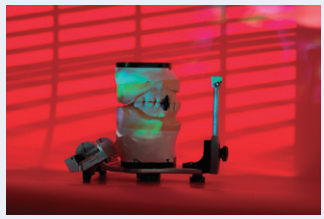
Facebow transfer (lateral view)



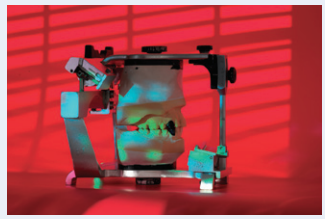
Facebow transfer (frontal view)



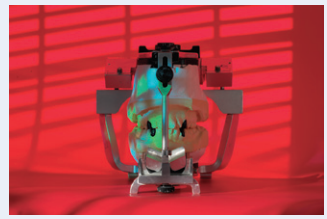
Bite registration



Mounted casts (lateral view)

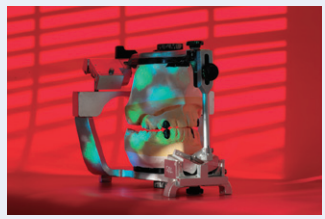


Mounted casts (frontal view)

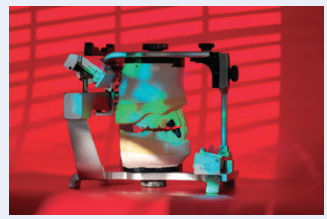


Shimstock contacts

Lateral excursion



Protrusion



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The **laboratory process** involves mounting casts onto a simulating device for reproducing, in three spatial planes, the occlusal situation of the patient's mouth. The degree of sophistication to which this is achieved depends on the chosen type of articulator, and the **meticulous steps** taken to avoid introducing errors at each stage of the mounting process. As discussed in Chapters 10 and 15, hinge and fixed value articulators assume no semblance to the relationship of the jaws, while fully adjustable types allow a wider range of adjustable values that are more representative of jaw movements. For most prosthodontic treatment, the most popular type of articulator is the **semi-adjustable Denar** with accompanying **earbow** type of **facebow** transfer. In this chapter the Denar articular is described for its use in occlusal analysis and treatment planning.

Pouring casts

The first stage is **pouring casts** from the impressions using high-quality, **minimum distortion** hard **plaster**. Any aberration of tooth anatomy will seriously distort the clinical scenario, leading to misleading interpretations and incorrect treatment planning.

Maxillary cast location

The **facebow** transfer, with the bite fork, locates the **maxillary cast** within the articulator to the **hinge axis** and ensures its **orientation** to the **horizontal plane** (external auditory meati or interpupillary line of the patient). The **anterior reference pointer**, 43 mm above the maxillary lateral incisor, ensures that the **reference plane** is adjusted accordingly.

Mandibular cast location

The **mandibular cast** is located to the **maxillary cast** in either **CO** or **CR**, at the chosen occlusal vertical dimension (**OVD**) using the occlusal records.

Mandibular excursions

After both casts of the arches are correctly and accurately mounted, protrusive and lateral excursions can be assessed. **Photographic documentation** showing **articulation paper marks** are useful for the technician to verify initial contact in CR, slide from CR to CO, non-working side interferences and guiding teeth in protrusion and lateral excursions, i.e. **canine guidance** or **group function**.

Adjusting contacts and OVD

Depending on the treatment plan and clinical prescription, any **trial selective occlusal adjustments** can be performed on the casts, and analysed, before carrying out irreversible adjustments in the mouth. Similarly, the **OVD can be increased**, and either an **occlusal splint** or a **temporary prosthesis** fabricated to the new OVD for assessing intra-oral occlusal tolerance.

Anterior diagnostic wax-up

If **anterior aesthetics** are to be restituted, additive diagnostic procedures such as **diagnostic wax-ups** are invaluable for assessing appearance and gaining the patient's acceptance. From the diagnostic wax-up, a **vacuum stent** can be made, which serves as an excellent template for intra-oral **mock-ups** with composite resins for **assessing aesthetic parameters** such as:

- Degree of **tooth display at rest**;
- Amount of the **tooth display during smiling**;
- **Parallelism of maxillary incisal plane** with curvature of mandibular lip during a relaxed smile;
- **Shade assessment**;
- **Tooth morphology**.

In addition, the diagnostic wax-up can be used to fabricate **surgical stents (with or without CBCT scans)** for precise **placement** of **implant** fixtures.

Broadrick flag

If the posterior dentition requires rehabilitation, a diagnostic wax-up can be carried out using the **Broadrick flag** to **restore** the **curves of Spee, Wilson and Monson**, thereby allowing posterior tooth disclusion during mandibular excursions.

Using the Broadrick flag technique assumes correct functional and aesthetic position of the mandibular incisors. An **anterior survey point** is chosen, usually the mandibular incisors, and using a **compass** (**opened 4 inches**), an arc is drawn on the 'flag'. The **posterior reference point** is either a molar, or if none is present, the condylar part of the articulator is selected, and another arc drawn to intersect the first. Using the two arcs as reference curves, wax is curved to restore the occlusal plane in three dimensions (curve of Monson). The completed wax-up can be used in a similar manner to the anterior wax-up as a **template** for temporary prostheses, and vacuum and surgical stents.

Custom incisal guidance table

A custom incisal table is used to copy either the **preoperative** or the **proposed anterior guidance** to the temporary or definitive restorations. Cold **cured acrylic resin** is placed on the **guide table**, and the articulator is moved in all excursions until the material has set to create a record of mandibular movements. When the **working cast** of the definitive restorations is mounted on the articulator, the table acts as a guide to shape the **palatal surfaces** of the restorations to conform to the mandibular movements.

Key points

- A semi-adjustable articulator is the most convenient and commonly used device for occlusal analysis and prosthodontic treatment.
- Mounting casts involves a facebow transfer with registration using interocclusal records at the correct OVD.
- Anterior wax-ups are an ideal method for aesthetic scrutiny without irreversible tooth preparation.
- The Broadrick flag technique is used for restoring the 3-D curve of Monson.
- A custom incisal table is used for copying anterior guidance for the definitive restorations.

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17 Occlusion: adjustment and splints

OCCLUSAL SPLINTS

Equilibrium

Occlusal stabilisation is questionable, and may be negated by neuromuscular adaptation

Adjust contacts

Removing non-working, CR, interfering and iatrogenic contacts before treatment

Clearance

Ensuring sufficient space for restorative materials in all excursions, especially for guiding teeth

Relieve stress

On implant-supported prostheses, periodontally involved and endodontically treated teeth, fractured teeth or restorations

OCCLUSAL SPLINTS

Michigan splint

Stabilising the occlusion and relieving symptoms

Bite raising appliance

Increasing the OVD

Dahl appliance

Altering the OVD by orthodontic movement

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After analysing the occlusion by performing a clinical examination and laboratory assessment, the next step is deciding whether any **occlusal adjustment** or **occlusal splints** are necessary before starting prosthodontic therapy.

Occlusal adjustment

Occlusal stabilisation by **occlusal adjustment (OA)** is a controversial topic. Before discussing opposing theories, if **TMD (temporomandibular disorder)** is suspected, differential diagnosis is essential to elucidate whether TMD symptoms originate due to **myogenous** or **bruxism** origins, or **pathology** of the **mandibular articular** region. If the latter is suspected, occlusal adjustment is futile.

However, if TMD problems originate from **myogenous** or **bruxism** causes, OA may or may not alleviate symptoms. There are **two schools of thought regarding OA**. The **first** states that **neuromuscular feedback** will adapt to any adjustments and therefore negate its effect. The **second** opinion is that OA can **stabilise the occlusion**, removing interferences that impede physiological mandibular excursions, and hence provide symptomatic relief. Whichever opinion one holds, in order to **prevent irreversible occlusal destruction**, it is probably prudent to avoid OA until further conclusive research is forthcoming.

Besides TMD reasons, **selective OA** is justified before starting restorative treatment. **Preoperative adjustments** can be invaluable in saving time and avoiding disappointment as treatment progresses, especially at the cementation stage to **'grind in'** the restoration(s), for example:

- Removing **non-working side interferences** causing lifting of the mandible on the working side;
- Ensuring **sufficient occlusal clearance** for restorative materials in all excursions (particularly for **guiding teeth**);
- If the tooth to be restored is the **initial contact in CR**;
- Eccentric contact(s) **preventing closure in CO**;
- **Extruded teeth**;
- Preventing **undue stress on implant-supported prostheses**;
- Relieving occlusal stress on **fractured teeth or restorations**;
- Eccentric contacts **exacerbating bruxism**;
- **Iatrogenic interferences** introduced by existing artificial prostheses;
- Relieving **periodontal trauma due to occlusion**;
- Reducing stress on **endodontically treated** teeth that are more susceptible to occlusal bite forces.

Occlusal stabilising splints

Various **designs of splint** are advocated depending on the clinical manifestations. The most popular is the full arch splint, e.g. **Michigan**, normally worn at night. The construction is of **heat-cured acrylic**, **2 mm** in thickness, with either **anterior or canine disclusion**. The important factor is that the interocclusal device be **periodically adjusted** until symptoms subside, or the treatment objective is achieved. Other varieties include **partial coverage** types that are contraindicated because they permit unwanted orthodontic tooth movement, while the soft varieties (or vacuum-formed splints) are less efficacious than the Michigan type. The disadvantage of splints is **lack of patient compliance**, which diminishes the potential beneficial effects of these appliances.

Innumerable studies have confirmed the efficacy of **occlusal stabilising appliances** for **reducing parafunctional** and **electromyographic** activity in conjunction with **mandibular repositioning**. Occlusal splints are prescribed for a variety of reasons including:

- **Tooth wear and bite raising appliances** (see below);
- **Protecting fragile or susceptible** restorations (especially all-ceramic restorations);
- **Retainers** following orthodontic or periodontal therapy;
- **Differential diagnosis of TMDs** (myogenous, bruxism or articular origin);
- **Reducing** clenching, bruxism, cheek biting, fractured teeth/restorations;
- **Controlling** stresses on implant-supported prostheses, trauma from occlusion;
- **Tempering** bruxism coexisting with comorbid syndromes (e.g. Parkinson's disease);
- **Supportive treatment** for secondary otalgia associated with clenching;
- **TMJ** disk derangement, clicking, locking, arthralgia, arthritis and myalgia;
- **Symptomatic relief** in certain types of migraine;
- **Relief** of smarting symptoms associated with **burning mouth syndrome (BMS)** using lingual splints.

Bite raising appliance

Tooth wear is accompanied by compensatory growth of the alveolus, termed **alveolar compensation**, that **maintains the OVD** but leaves little, or **no interocclusal space** for replacing the lost enamel and dentine. One method for gaining interocclusal clearance is using a **bite raising appliance** for assessing whether the patient can tolerate an increase in the OVD, before providing reparative restorations.

The Dahl appliance

The principle of the **Dahl orthodontic appliance** is to allow **periodontal growth of the posterior dentition** and **intrusion of the anterior teeth**, thereby creating room in the anterior region for restorative materials to replace the lost tooth substrate at a new OVD. This was originally achieved by a **removable palatal bite-raising platform** on the anterior teeth, causing posterior disocclusion, and allowing **overeruption of the posterior teeth (periodontal growth)** for re-establishing the bite. However, to overcome poor patient compliance, **fixed restorations** (either temporary or permanent), can instead be cemented onto the palatal surfaces of the anterior teeth to achieve a similar objective, with better outcomes.

Key points

- Occlusal stabilisation by occlusal adjustment (OA) is contentious.
- Selective OA before starting treatment is prudent and avoids future complications.
- Occlusal splints are inexpensive and non-invasive treatment modalities.
- Occlusal splints can alleviate parafunctional habits and reduce muscular spasms.
- Bite raising or Dahl appliances are useful for establishing a new OVD by interocclusal clearance for restorative materials following tooth wear.

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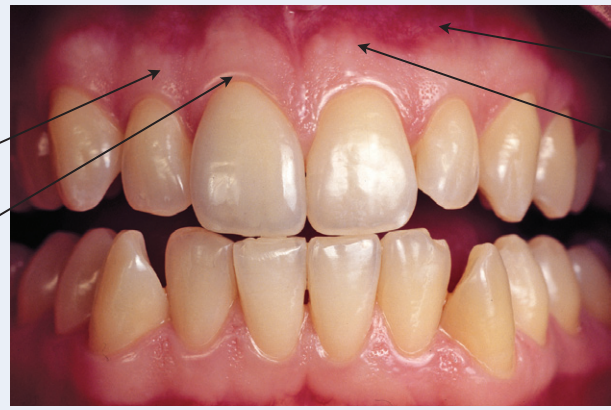
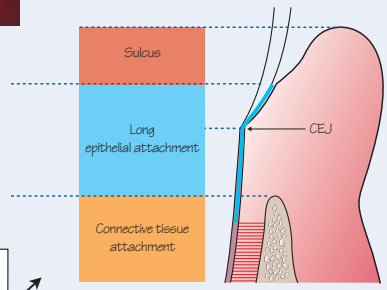
18 The dentogingival apparatus

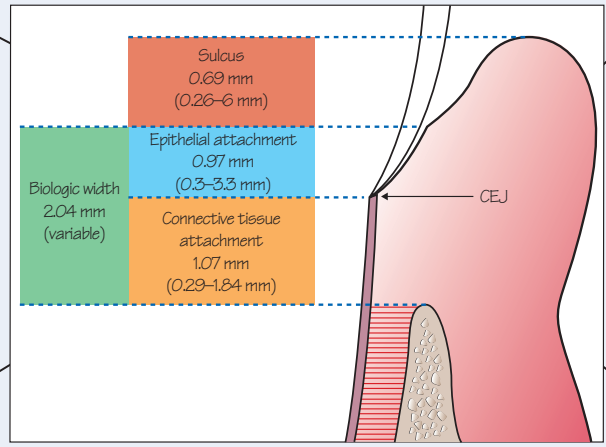


Superficial anatomy

BW variations: is smaller around anterior teeth



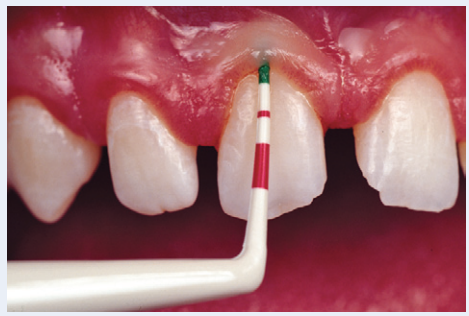
BW variations: long EA



Cross-section dentogingival apparatus landmarks

BW variations: apical location of BW on left lateral due to defective crown

BW variations: passive eruption (short clinical crowns)



Bone sounding for BW dimension

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Periodontal health is essential for successful prosthodontic treatment outcomes. This chapter describes basic periodontal aspects requiring analysis before embarking on restorative treatment.

Superficial anatomy

Viewed from the **facial** or **buccal aspect**, the soft tissue envelope around the teeth is distinguished into the **gingiva** and **alveolar mucosa**. Starting from the tooth junction, the gingiva is further divided into the **free gingival margin (FGM)** and **attached gingiva**, terminating apically at the **mucogingival** junction with the alveolar mucosa. The **attached** gingiva is **keratinised**, tenacious and resilient to withstand masticatory function, while the alveolar mucosa is **unattached** and **non-keratinised**.

The **dimensions** and **texture** of the **attached gingiva** vary enormously, not only between individuals, but also around specific teeth. The **width** (apico-coronal dimension) varies from **0.5 mm to 8 mm**, and the average **thickness** (bucco-lingual dimension) is **1.4 mm**. The function of the attached gingiva is to **protect** the soft tissues during oral function, and its absence, especially around **implants**, has been shown to increase the propensity to inflammation.

Dentogingival apparatus

In cross-section, the **dentogingival** apparatus can be divided into three components: **epithelium**, **connective tissue** and **bone**. In a **healthy periodontium**, the **sulcus** starts at the **FGM** and ends at the **epithelial attachment (EA)**. The depth of the sulcus (or **gingival crevice**) varies from **0.3 mm to 6 mm** depending on numerous factors such as location on the tooth (**deeper sulcus interproximally**). The EA extends apically from the sulcus to the **cemento-enamel junction (CEJ)**, ranging from **0.3 mm to 3.3 mm**. The **connective tissue attachment (CTA)** is apical to the EA and terminates at the **alveolar bone crest (ABC)** housing the teeth. The CTA shows the least variance of the dentogingival apparatus, i.e. **0.3 mm to 1.8 mm**. The combined linear measurements of the EA and the CTA is termed the **biologic width (BW)**, averaging **2.04 mm.**

Biologic width

The frequently quoted measurement of the biologic width (BW) as 2.04 mm is based on **average** measurement of the dentogingival apparatus from cadavers:

- Sulcus depth = **0.69 mm**;
- EA = **0.97 mm**;
- CTA = **1.07 mm**;
- **EA + CTA (biologic width)** = **2.04 mm**.

The significance of the BW is that it is **nature's approach to protecting** the most important part of the dentogingival apparatus, i.e. the **periodontal ligament** and the **ABC**, which ensures survival of a tooth. This **soft tissue shield** guards against **mechanical** and **bacterial** insult. However, as for any shield, its efficacy is diminished if violated or damaged, placing the tooth (together with any restorations) in a precarious situation.

The salient points about the BW can be summarised as follows:

- **Present around every tooth**;
- **Nature's soft tissue shield** for ensuring tooth survival;
- **2.04 mm** is an **average dimension, not applicable to every patient** or every tooth;
- It is essential to preserve the BW and **prevent** its **violation** during clinical procedures;
- **Differential diagnosis** is necessary for **variations** of BW.

BW variations

The biologic width is a **physiological 3-D** concept, sometimes referred to as the **biologic space**. At present, the **minimum dimension of the BW for health is unknown**; it can be as small as **0.6 mm**. The dimension of the BW varies depending on the **type of tooth** and the **location around a tooth**; some differences are listed below:

- **Type of tooth**
  Incisors and canines = 1.75 mm;
  Premolars = 1.97 mm;
  Molars = 2.08 mm.
- **Population variations**
  85% normal relationship of ABC and EA to CEJ;
  13% ABC and EA in an apical position to norm – larger BW;
  2% ABC and EA in a coronal position to norm – smaller BW.
- **Apical position of EA** – pseudo-healing following episodes of periodontitis and/or mechanical or surgical trauma;
- **Passive** (apical location of BW) and **altered passive eruption** (coronal location of EA with **short clinical crowns**);
- **Restored teeth** have a larger BW;
- **Implants** – BW is located more apically compared to natural teeth.

Methods for determining BW dimension

To **preserve the BW** it is essential to determine its dimension and location. Since it is impossible to determine the BW by visual inspection, the methods available include:

- **Tactile** – most popular method by **sounding bone** (along long axis of tooth) and **transgingival probing** (perpendicular to tooth). Requires local anaesthetic, invasive, erratic reading in presence of inflammation or presence of a long EA;
- **Parallel profile radiography** – questionable unnecessary radiation exposure;
- **Ultrasound** – non-invasive, variable readings, which are averaged for a given tooth;
- **Soft tissue cone beam computed tomography (ST-CBCT)** – CBCT scan taken with photographic cheek retractors to displace lips and cheeks, and requesting patient to place tongue to floor or back of the mouth to allow visualisation of the **gingival soft tissues** (buccal and palatal/lingual). Non-invasive, **precise** measurements of **both soft tissues and bone** in both **axial and perpendicular axis** to tooth. Questionable unnecessary radiation exposure, unable to distinguish between EA and CTA or inflamed and healthy tissues.

Key points

- The dentogingival apparatus consists of epithelium, connective tissue and bone, and its health is paramount for successful prosthodontic treatment.
- It is essential to determine dimension and location of BW before starting restorative treatment.
- The most popular methods for determining BW are tactile and ST-CBCT.

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19 Prosthodontic considerations

Tooth shape	Gingival scallop	Distance from interproximal bone crest to mid-facial bone crest (mm)
Square	Flat	2.1
Oval	Scalloped	2.8
Triangle	Pronounced scallop	4.1

Black triangles

Incomplete papilla fill

Maxillary teeth flaring

Mandibular teeth flaring

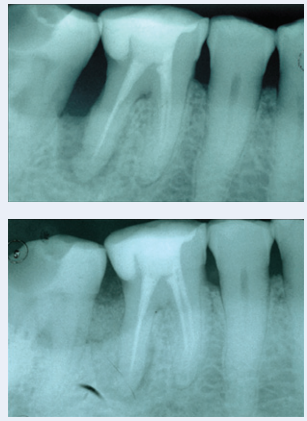
Peri-implantitis (preoperative)

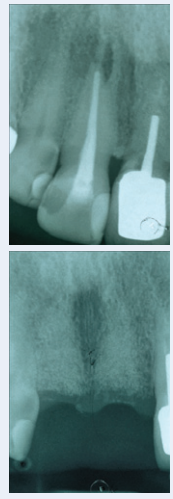
Peri-implantitis (postoperative)

BW violation: inflammation around right central incisor crown

BW violation: recession around existing defective crowns

REGENERATIVE MEASURES





PPS

PPS (periodontal plastic surgery) is used to expose teeth, e.g. crown lengthening or cover exposed tooth roots, e.g. soft tissue grafting

GBR

GBR (guided bone regeneration) is used for correcting bony defects, or bone augmentation before implant placement

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Achieving and maintaining **periodontal heath** is influenced by numerous factors, including **disruption of the biofilm** by **scaling/root planing**, **surgery**, **chemotherapy** (local and systemic)**, patient factors** (oral hygiene, constitutional, systemic illness, habits) and degree of **operative trauma** during clinical procedures. A **paradigm shift** is also emerging regarding the **treatment of periodontal disease**. Conventional scaling, root planing and surgery for eliminating pockets is being replaced by a more minimal, non-invasive approach of **full-mouth ultrasonic debridement** for **disrupting the biofilm** and thereby achieving **disinfection of the root**. Periodontal health is essential before starting prosthodontic treatment, and is a constituent of the **health**, **function**, **aesthetic** (**HFA**) triad.

Periodontal biotypes and bioforms

The **periodontal biotype** plays a significant role when planning prosthodontic and implant therapies. Periodontal biotypes represent gingival texture and architecture around teeth and are classified as:

- **Thin-scalloped** – delicate, prone to **gingival recession**, **dehiscences** and **fenestrations**;
- **Thick-flat** – fibrotic, resilient, prone to **periodontal pocket formation**;
- **Medium** – intermediate between the above two extremes.

The **periodontal bioform** describes the degree of gingival scallop around teeth, which is primarily dictated by **tooth shape**, and can broadly be categorised as **square**, **oval** or **triangular**, corresponding to the **flat**, **scalloped** or **pronounced scalloped** bioforms, respectively.

Contact points

The relationship of the **contact point** (either of natural teeth or artificial prostheses) to the **interproximal alveolar bone crest** determines the amount of interproximal gingival **papilla fill**. If the distance is **5 mm or less**, total papilla fill is evident in the gingival embrasures. If the distance is **greater than 5 mm**, incomplete papilla fill is observed, especially with thin biotypes, colloquially referred to as **'black triangles'**. However, to achieve complete papilla fill between **two adjacent dental implants**, the distance required is less than for natural teeth, i.e. **<3 mm**.

Trauma from occlusion

Trauma from occlusion is a major **contributing factor** in periodontal disease and can present as bone loss without periodontal pocket formation. Trauma from occlusion can be:

- **Primary trauma** – with an **adequate (healthy) periodontium**;
- **Secondary trauma** – **inadequate (diseased) periodontium,** resulting in teeth that are incapable of withstanding occlusal forces in an axial direction, leading to **migration**, **fremitus** and **flaring**. The treatment depends on the severity of trauma and includes **orthodontic alignment** (to correct osseous defects and improve crown-to-root ratios), **occlusal equilibrium**, **occlusal stabilising splints**, **periodontal splints**, **bone regenerative therapies**, **and implants** (for replacing strategic teeth for occlusal stabilisation).

Biologic width violation

The previous chapter discussed the significance of the **biologic width (BW)**. Many clinical procedures can potentially violate the BW, and therefore compromise a healthy periodontium and success of an artificial prosthesis. The consequences of BW violation depend on the **host response** and include:

- **Adaptation** – a new BW forms in a more apical position to restore health of the periodontium;
- **Persistent inflammation** – requires orthodontic extrusion, or bone resection by a surgical approach to restore the BW;
- **Gingival recession** – causing **asymmetrical gingival zeniths**, 'black triangles', especially with thin-scalloped biotypes;
- **Pocket formation** – common with thick-flat biotypes;
- **Perio-endodontic lesions** – abscesses or chronic periapical pathology.

Peri-implantitis

Periodontal diseases also plague dental implants. Inflammation around implants is classified as:

- **Mucositis** – reversible inflammation without bone loss;
- **Peri-implantitis** – inflammation combined with irreversible bone loss around implants due to infection, more prevalent with partially dentate ridges due to cross-infection from adjacent periodontally involved teeth, compared to edentulous arches. Peri-implantitis is **time dependent**, affecting a small number of patients following implant therapy. The **risk factors** associated with this condition are unclear, but links have been postulated with **systemic illness** (e.g. diabetes, osteoporosis, obesity), **habits** (e.g. smoking, drinking extremely hot fluids), **local factors** (e.g. bone quality and quantity, reduced blood supply) and implant design and surface coatings.

Periodontal plastic surgery

Periodontal plastic surgery (PPS) is indicated for correcting deformities caused by periodontal disease to restore function, aesthetics and longevity of restorative therapy. PPS is divided into two categories:

- **Exposing tooth – crown lengthening** for improving crown-to-root ratio, enhancing aesthetics (altering width-length ratio of tooth or reducing gingival display during smiling), rectifying altered passive eruption, pocket reduction, re-establishing BW, and restitution of erratic gingival contours;
- **Gingival grafting** – increasing the width of attached gingiva or root coverage according to **Miller's classification**. Soft tissue grafts are usually harvested from the palate (membranes can also be used) and sutured in situ at the recipient site(s).

Regenerative therapy

Regenerative therapies involve **augmenting bone volume** lost as a result of periodontal disease for **repairing bony defects**, or **establishing an adequate platform** for eventual **implant placement**. The principles for **guided bone regeneration (GBR)** are to retard epithelial growth to allow time for bone formation. This is achieved by using a combination of **membranes** (resorbable and non-resorbable) and **bone grafting materials**, such as **autogenous bone** (from host, e.g. nasal spine, mandible or iliac crest), **allografts** (from animals, e.g. bovine-derived prion-free tissue) and **xenografts** (synthetic materials, e.g. particulate ceramics and hydroxyapatite).

Key points

- Factors influencing periodontal health include periodontal biotypes, contact points, trauma from occlusion and BW violation.
- Corrective measures include periodontal plastic surgery and regenerative therapies.
- Peri-implantitis, although affecting a minority of patients with implants, is a significant concern for implant survival rates.

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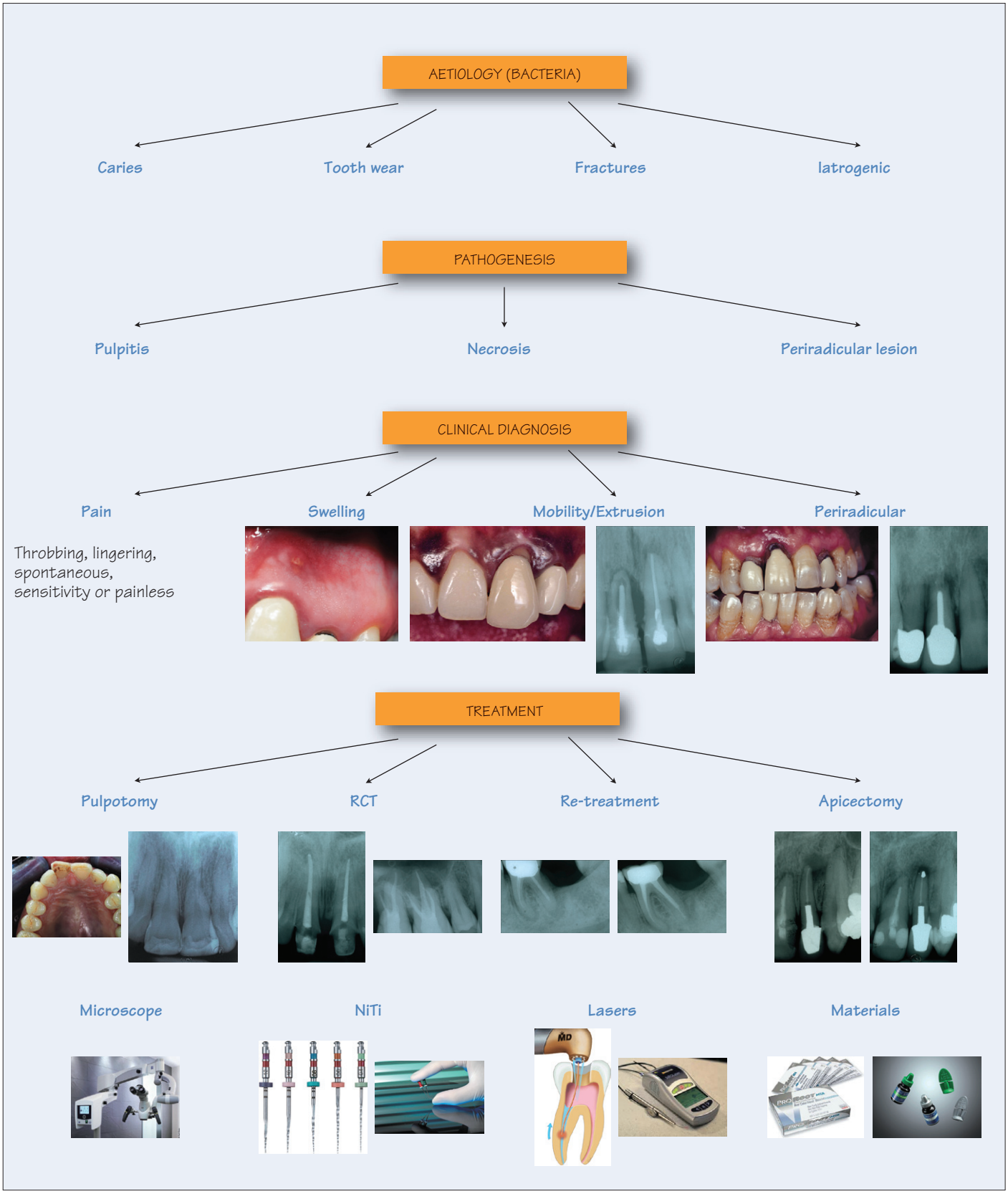
20 The dental pulp



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A healthy **dental pulp** ensures **survival of a natural tooth** and any artificial **restorations**. The sections below discuss recent thinking and developments for clinical management of pulpal diseases.

Aetiology

Pulpal diseases are **bacterial** in origin, from the resident oral **microbiota**, either directly or indirectly. Some causes include:

- **Caries –** direct bacterial assault of the pulp;
- **Tooth wear –** eventual pulpal pathosis due to attrition, abrasion, erosion and abfraction;
- **Tooth fractures** – pulp exposure due to extra-oral **accidents** or **masticatory misadventures**;
- **Iatrogenic** – pulp exposure during restorative procedures.

Examples of microbes found in **root canals** and **periradicular** lesions include *Enterococcus faecalis*, *Candida albicans*, *Actinomyces israelii*, *Propionibacterium propionicum*, cytomegalovirus and the Epstein–Barr virus.

Pathogenesis

Whatever the cause, microorganisms initiate an **inflammatory response (pulpitis)**. **Bacterial toxins** precede bacterial invasion, causing a **vascular** response by releasing **cytokines** and **mediators**. If the bacterial insult is confined to the **hard tissues**, a **reparative** and **protective secondary dentine** barrier is formed. If the pulp is **exposed**, formation of a **soft tissue barrier** is impossible since the pulp is devoid of epithelial cells. Therefore, the bacterial invasion and proliferation is profuse, leading to colonisation of the **root canal system** and subsequently the **periradicular areas**. The infected periradicular areas react with a **protective response** by bone resorption to **contain** and **eliminate** the infection, which is visible as an **osteolytic bone lesion (periapical lesion)** on a radiograph.

Clinical manifestations and diagnosis

Precise and **efficient diagnosis** is essential for determining the appropriate treatment. Differential diagnosis includes **pulpitis** (reversible and irreversible) and **necrosis** (partial or complete) with or without **periradicular** involvement. A major clinical challenge is differentiating between **reversible and irreversible pulpitis**; at present, this decision is mainly based on guesswork. Some symptoms and tests for pulpal diseases include:

- **Pain** – throbbing, lingering, spontaneous, tender to touch or tooth sensitivity;
- **Painless** – e.g. complete pulpal necrosis in older patients;
- **Swelling** – intra- and extra-oral;
- **Percussion sensitivity – TTP** (tender to percussion);
- **Tooth mobility**;
- **Extrusion –** combination of periodontal/endodontic lesions;
- **Pulp vitality tests –** thermal, electrical, chemical, pulse oximetry (see Chapter 5);
- **Periapical radiolucency** – assessed by radiographic or CBCT evaluation;
- **Systemic** – fever, lethargy, malaise, anxiety.

Treatment modalities

Management of the damaged pulp is predominantly concerned with **reducing or eliminating bacteria**. Some options are summarised below.

- **Pulpotomy with pulp capping** – indicated for acute traumas of healthy pulps in young individuals (with an enhanced regenerative potential), for encouraging pulp **regeneration** or **repair** by formation of **secondary dentine** using a pulp-capping agent, e.g. **calcium hydroxide**.
- **Pulpectomy** with **root canal therapy (RCT)** – extirpation of infected pulps. RCT has the following objectives: **debridement**, **shaping, disinfecting** and **obturating** the root canal system.

Failure of endodontic treatment is attributed to lack of **asepsis** during treatment, **failure to eliminate infection** from the root canal and/or periapical areas, or subsequent **leakage** due to poor obturation or defective coronal restorations. In these circumstances, the treatment options are:

- **Re-treatment** with a new, correctly fitting coronal restoration;
- **Surgical endodontics** – **apicectomy** and **retrograde filling**;
- **Extraction** with subsequent **implant(s)**. Implants may also be considered for failed apicectomies or complex re-treatment cases.

Technological adjuncts

The last two decades have witnessed a burgeoning of technological advances for improving endodontic therapy, including the **operating microscope**, **ultrasonic devices**, **electronic apex locators**, **lasers**, **light-activated disinfection**, **NiTi** (nickel-titanium) files and **miniaturised instruments** for working with magnifications up to ×32. In addition, newer materials such as **dentine bonding agents**, Biodentine (Septodont) and **mineral trioxide aggregate (MTA)** have improved treatment outcomes.

Endodontic controversies

As with many disciplines, the schism between **clinicians** and **researchers** leads to contradictory views. Advancements in **biologically based knowledge** are slowly adopted into **clinical practice**. Furthermore, **success** or **failure** is in the eyes of the beholder. Many different criteria may be used to assess endodontic outcomes, e.g. absence of pain, survival of the tooth, survival of a restoration, apical bone regeneration, or elimination of infection.

Some current controversies include:

- Whether to leave or remove the **smear layer**;
- **One-** vs **two-appointment** RCT;
- Ideal measures for promoting **regeneration** (of pulp) or **repair** (secondary dentine), e.g. using **bioactive** substances;
- Importance of **coronal** vs **apical seal** (i.e. significance of **location of microorganisms** – apical or coronal part of root canal);
- **Direct** vs **indirect pulp capping** (step-wise excavation);
- Efficacy of **disinfecting agents** – e.g. sodium hypochlorite, chlorhexidine, calcium hydroxide, tetracycline isomer compound;
- Concept of **sterile periradicular granulomas**;
- **Apical terminus location** and healing with cementum-like tissue;
- **Lateral condensation** vs **vertical compaction** obturation.

Key points

- Understanding the biological processes ensures correct diagnosis, and selection of the most appropriate endodontic treatment.
- Technological advances have resulted in more predictable therapy, but further research is required to resolve current controversies.

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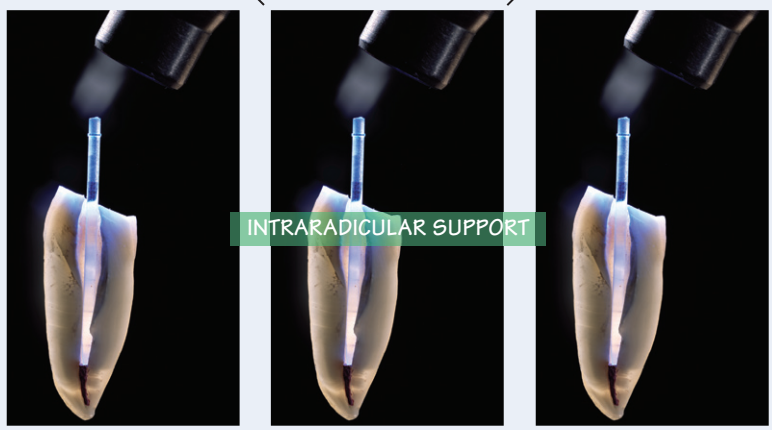
21 Intraradicular support

Is a post necessary?
Is the remaining coronal dentine sufficient to support an extracoronal restoration?

INDICATIONS

Tooth anatomy
Adequate alveolar bone support
Post length : crown length ratio
Root length
Post width
Ferrule effect

GUIDELINES



TYPES

PLACEMENT

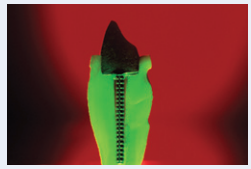
Cast metal

Steel

Zirconia

Canal prep

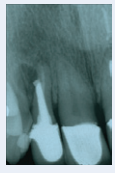
Radiograph of GP filling and metal post


Cast metal post and core

Ribbon

Carbon fibre

Glass fibre


Perforation

Posts in premolars

Posts in molars

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Posts, or **intraradicular supports**, do not strengthen or reinforce teeth. In fact the opposite is true: removal of dentine from a root canal to accommodate a post **weakens the structural integrity** of the root. Heavily broken teeth due to trauma or caries, with or without a root filling, may present with insufficient tooth structure to retain an **extracoronal definitive restoration**. Therefore, the purpose of a post and core is to gain **intraradicular support** for the definitive restoration.

Indication for posts

If there is **sufficient remaining coronal dentine** to support a restoration, **a post is superfluous**. This is especially true for **molars** with considerable amounts of dentine or large pulp chambers. At the other extreme, the **incisors** have smaller amounts of coronal dentine, which is reduced following trauma, caries or endodontic abscess cavities. In these circumstances, a post is essential for retention of a permanent restoration. Furthermore, **root-filled teeth** have **reduced proprioceptive response**, and are therefore more vulnerable to masticatory and occlusal forces.

Guidelines for post placement

Before placing a post, certain criteria must be fulfilled in order to ensure its survival and that of the overlying extracoronal restoration. Some factors to consider are:

- **Tooth anatomy**:
  Molars – choose the largest and straightest canal for post placement, i.e. distal canals of mandibular molars and palatal canals of maxillary molars. Placing posts in curved root canals often results in perforations into the periodontal ligament or alveolar bone;
  Premolars – smaller pulp chambers, with tapering roots exhibiting thin mesiodistal cross-section with proximal invaginations;
  Incisors and **canines** – post is unnecessary if sufficient coronal dentine is present. Mandibular incisors have thin, tapering and narrow mesiodistal root morphology;
- Sufficient **alveolar bone support** encompassing at least half of post length into the root;
- Minimum **1 : 1 post length/crown length ratio**;
- **Root length** long enough to accommodate a 4–5 mm apical root filing seal and ½ to ⅔ of the post length;
- **Post width** not exceeding ⅓ of root width at narrowest point and 1 mm of remaining circumferential dentine;
- **Ferrule effect** – at least 1.5 mm height and width of remaining coronal dentine.

Ideal properties of a post

The ideal properties of a post can be summarised as follows. Similar **mechanical and physical properties** as natural teeth, e.g. modulus of elasticity, compressive strength, coefficient of thermal expansion and optical characteristics. The post material should be **biocompatible**, non-corrosive and **hypo-allergenic**, should minimise **microleakage**, prevent root or restoration **fractures** (both **cohesive** and **adhesive fractures**) and exhibit favourable **clinical handling** and ease of use. The dental market is inundated with posts of **different materials**, **shapes**, **configurations**, **surface finishes** and **colours**. There is no single post that has all the properties for every clinical situation, and often a compromise is necessary.

Choice of post

Posts can broadly be categorised as **custom-made** or **prefabricated**. **Custom posts** are usually made of **cast metal** or **alumina ceramics** by an **indirect technique**. This is useful for making a **unified post and core** to replace extensive coronal dentine loss. However, the process involves **two visits** to the surgery with the possibility of **contamination** of the root canal due to provisional cement failure or defective temporary restorations.

Prefabricated posts are the most popular type, offering expediency, single-visit placement and immediate preparation of core build-ups, and are available in a large selection of materials and designs:

- **Metal**, e.g. stainless steel, brass, titanium. Disadvantages include poor aesthetics, root fracture, corrosion and nickel sensitivity;
- **Ceramics**, e.g. alumina, zirconia or porcelain fused to metal. High flexural strength and fracture toughness, favourable aesthetics. However, the drawbacks are difficult retrievability and propensity for root fracture;
- **Fibre** posts, e.g. pliable ribbon, glass, quartz or carbon fibre. Flexible, similar physical properties to dentine, e.g. modulus of elasticity of dentine = **15 GPa**. Highly aesthetic (light-transmitting), easily retrievable, bonding to dentine with dentine bonding agents, and mitigate root fracture;
- **Design** – tapered types require less dentine removal, but offer poorer retention compared to parallel designs. The surface finish can be smooth or serrated and may incorporate cement vents for luting agents. The threaded or screw posts (**active posts**) offer enhanced retention, but at the expense of root fracture susceptibility due to dentine stresses.

Canal preparation and post cementation

Placing a post requires shaping the canal to accommodate the post geometry by removing a part of the root filling (usually gutta-percha). A thorough knowledge of root anatomy is essential before canal preparation. The two methods for **gutta-percha removal** are thermal and mechanical. The **thermal approach** is tedious but less traumatic. The **mechanical approach** involves using rotary instruments such as Gates-Glidden burs or P-type reamers, which may inadvertently disrupt the **apical seal** or result in **lateral perforation**.

The majority of posts are **passive**, requiring a **luting agent** for cementation into the root canal. **Zinc phosphate cement** has the longest clinical history but is prone to leakage. **Glass-ionomers** offer dentine adhesion, but their poor mechanical properties may cause cement failure leading to microleakage. **Composite-based resins** have high compressive strength and dentine adhesion with dentine bonding agents, but are technique sensitive.

Key points

- Careful consideration is required before placing a post, as the latter weakens the tooth.
- No ideal post system exists, and a pragmatic approach is necessary.
- Meticulous root canal preparation and choice of cement are essential for long-term post and definitive restoration survival.

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22 Coronal support: core build-up

Retain maximum amount of tooth structure
Preserve marginal ridges
Incorporate ferrule effect

PREREQUISITE

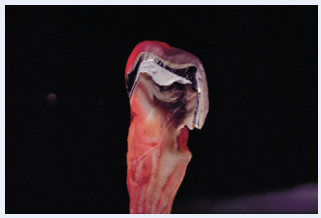
Amalgam
Resin-based composite
Glass ionomer
Ceramics
Cast gold

MATERIALS

CORE BUILD-UP

VITAL TEETH

NON-VITAL TEETH



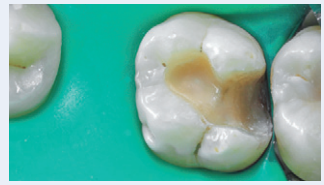
Amalgam

Composite

Cast gold

Ceramic

Fill-in with glass ionomer



Fill-in with flowable composite

Amalgam

Composite

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The purpose of a **core build-up** is to provide **retention** and **resistance** for definitive, usually extracoronal, restorations. The final restoration can be **partial** or **full coverage** depending on the amount of residual tooth substrate. **Cores** can be built up on either **vital** or **non-vital** teeth, which have previously received a post to gain additional **intraradicular support** from the endodontically treated root.

Ideal properties of a core build-up material

At present, a single restorative material does not offer all the ideal properties of a core build-up material, which are:

- Adequate **physical properties (flexural and compressive strength)** to resist intra-oral forces;
- **Non-allergenic**;
- **Biocompatible**;
- **Preventing microleakage** of oral fluids at core-tooth interface;
- **Chemical adhesion or bonding** to tooth substrate, both enamel and dentine;
- Similar **thermal properties** to natural teeth (**coefficient of thermal expansion** and **contraction**);
- Minimum **water absorption**;
- **Dimensionally stable**;
- **Cariostatic**;
- **Ease of manipulation**.

Materials for core build-up

The essential factor for a **successful and long-lasting core**, irrespective of the material used, is ensuring that at least **1.5 mm of dentine** is present for the **ferrule effect**. The most popular **materials for core** build-ups are amalgam, resin-based composite, glass ionomer, ceramics and cast alloys.

Amalgam has traditionally been used as a build-up material, offering **excellent strength**, **low solubility** and **bonding** by micro-mechanical retention to dentine using dentine bonding agents (**DBA**). The disadvantages are **poor aesthetics**, a **protracted setting time** requiring a second visit for preparation of the core, and patient concerns regarding its possible **toxicity**, a doubt refuted by scientific research.

Resin-based composites offer **superior aesthetics** and the ability to **bond to dentine** with DBA, and the **flowable** varieties allow ease of manipulation, especially for cementing posts in root canals. However, their drawbacks are **polymerisation shrinkage**, **hygroscopic expansion**, **incompatibility with eugenol** root-filling materials and **technique-sensitive** protocols.

Glass ionomers have the advantage of **chemical adhesion with dentine**, but their poor physical properties (**low tensile and compressive strengths**) are incapable of withstanding intra-oral forces. Therefore, their use is limited to **filling in** small defects, and they are not recommended for bulk build-ups.

Ceramics and **cast alloys** require an indirect technique and are reserved for cores with intraradicular posts, offering a **unified post and core complex**. **Cast gold** is resilient but has poor aesthetics beneath highly translucent all-ceramic crowns. Also, certain types of ceramics can be fused onto **zirconia posts** with excellent aesthetics. However, zirconia posts are stiff and difficult to retrieve if there are endodontic complications requiring re-root treatment.

Core build-up for vital teeth

Various methods are available for building a foundation for teeth that have lost enamel and dentine due to trauma, caries or previously failed fillings. The two crucial factors for cores on vital teeth are, first, to **preserve the maximum amount of healthy tooth** and, second, **to prevent pulpal involvement**. The importance of keeping the remaining tooth substrate is maintaining **tooth stiffness**, which depends on **preservation of the marginal ridges**. If the latter are lost, tooth stiffness is severely compromised, requiring either **cuspal coverage (onlay)**, or a **full coverage crown**.

The techniques for retaining cores on vital teeth include:

- **Pins** – questionable due to dentine crazing, and the possibility of inadvertent perforation into the pulp and periodontium;
- **Cavity modification** – judicious and strategic creation of undercuts, slots and grooves to retain the build-up material;
- **Dentine bonding agents** – for enhancing adhesion of amalgam and resin-based composites to coronal dentine;
- **Luting agents** – bonding to dentine, e.g. amalgam with wet zinc phosphate or glass ionomers.

Core build-up for non-vital teeth

Materials for core build-up on non-vital teeth are similar to that for vital teeth. The **ferrule effect** is also applicable for non-vital teeth. However, since additional support is gained from intraradicular posts, the fundamental issue to address is **minimising material interfaces**. This means that materials of the post/core complex should have similar properties. When **similar materials** are used there is **less stress concentration** at the interfaces and **reduced microleakage**; such a post/core complex is **structurally** better placed to withstand intra-oral forces. This is the rationale for fabricating a **unified post/core complex** using an **indirect technique** with either cast alloys or ceramics.

With the **direct technique**, a post/core complex is made during a single visit, but the different material interfaces are a compromise, with poorer mechanical properties. Therefore, when using a direct approach, **precise clinical procedures** and appropriate **material selection** are essential for ensuring longevity of the post/core complex, and the subsequent permanent restoration.

Key points

- Core build-ups on vital and non-vital teeth are used to provide retention and resistance for permanent restorations.
- It is essential to preserve as much natural tooth substrate as possible, incorporating the ferrule to maintain structural integrity.
- There is no ideal material for a core build-up.
- Cores on vital teeth should avoid pulpal involvement.
- A unified post/core complex is preferred for non-vital teeth, because it avoids material interfaces.

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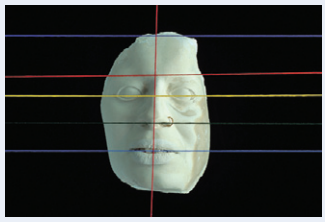
23 Anterior dental aesthetics: basic principles

FACIAL



Frontal facial view

Sagittal facial view

Interpupillary line parallel to incisal plane

Rickett's E-plane

DENTOFACIAL

Lip length

Age

Race

Sex

DENTAL

Width/length ratio

Axial inclination

Incisal embrasures

Width progression

GINGIVAL

Gingival exposure

Thick periodontal bioform

Black triangles

GAL class II

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Anterior dental aesthetics is primarily concerned with the appearance of the **maxillary anterior six teeth**. The majority of research has been directed towards the size, shape and alignment of the maxillary incisors and canines, their relationship to each other and the antagonist dentition, and to the surrounding soft tissues including the gingivae, lips and facial features. Dental aesthetics is best analysed by considering the **face** and then **zooming closer to the dental elements**.

Facial perspective

The facial perceptive can be divided into **frontal** and **sagittal** views. From the **frontal view**, the key features are:

- **Imaginary horizontal parallel lines** acting as **cohesive forces** for **facial symmetry**;
- **Facial midline**, perpendicular to horizontal lines, acting as **segregative force** to add interest to the facial composition;
- The **interpupillary line** is used as a reference for assessing the **inclination of the incisal plane**.

From the **sagittal (profile) view**, the analysis consists of:

- **Imaginary horizontal parallel lines**;
- **Frankfurt horizontal plane**;
- **Ricketts' E-plane**;
- **Steiner and Burstone lines**;
- **Naso-labial angle**.

Dentofacial perspective

Zooming closer, the **dentofacial composition** concentrates on the **teeth** and their **relationship to the surrounding soft tissues** in **static** and **dynamic muscular positions**.

The static position is a **habitual** (not relaxed) state, the lips are slightly parted with **minimal muscular activity** and the teeth are out of occlusion. The degree of tooth exposure is determined by the **LARS** factor:

- **Lip length (maxillary)** – varies from **10 to 36 mm**. Short lip = greater maxillary tooth exposure. Long lip = greater mandibular tooth exposure;
- **Age** – **youthfulness** equates to greater **maxillary tooth display**, while reduced muscular tonicity of the lip musculature in **advancing years** results in less maxillary and **greater mandibular tooth display**;
- **Race** – increasing maxillary tooth display from Caucasians, Asians to Blacks;
- **Sex** – **females have shorter maxillary lips** and display **more** of the **maxillary teeth** compared to men.

The dynamic positions are **relaxed** and **exaggerated smiles**. Some points to consider are:

- **Smile arc (line or curvature)** – imaginary line of the **incisal edges** of the maxillary teeth, which should be **parallel** to the **concave curvature of the mandibular lip**;
- **Bilateral negative space (buccal corridor)** – space separating the teeth from the corners of the lips;
- **Phonetics** – positions of the teeth relative to the soft tissues (lips and tongue) for proper pronunciation of sounds, for example:
  'M' – habitual muscular position of lips;
  'F' and 'V' – buccal surface of maxillary incisors contact mucosal (not cutaneous) part of lower lip;
  'S' – vertical dimension of speech or edge-to-edge position of the upper and lower incisors;
  'TH' – tongue touches palatal aspect of maxillary teeth.

Dental perspective

The dental perspective is concerned with **tooth shape**, **dimensions** and **alignment** and **progressive width proportions** between the maxillary incisors and canines. Some aspects include:

- **Shape** – genetically determined;
- **Size** – the width/length of teeth is referred to as the **w/l ratio** or its value as a percentage. The w/l ratio for **narrow teeth** can be as small as **60%** and for **wide teeth** greater than **100%**;
- **Alignment** – **intra-arch** positioning and **axial inclination**;
- **Incisal embrasures** – angles between the incisal edges or tips of teeth, influenced by the degree of tooth wear. Incisal embrasure angles increase from the anterior to the posterior teeth;
- **Width progression** – traversing distally from the centrals to the canines in specified increments or percentage widths of the teeth;
- **Overjet** (horizontal: ideal 2.7 mm) **and overbite** (vertical: ideal 4.0 mm).

Gingival perspective

The **gingival architecture** surrounding the teeth is determined by the undulations of the underlying bone and the morphology and size of the teeth. Gingival considerations include:

- **Gingival exposure** – refers to the amount of gingiva visible between the gingival zeniths of the maxillary teeth and the lower border of the maxillary lip during a relaxed smile. The amount of tolerable exposure is around 3 mm;
- **Periodontal biotype** – the texture of the attached gingivae, classified as thick, normal or thin;
- **Periodontal bioform** – degree of gingival scallop, categorised as highly scalloped, normal or flat;
- **Gingival embrasures** – amount of interproximal gingival papilla fill, linked to the **distance of the contact points to the interproximal osseous crest**. A distance of **less than 5 mm** ensures **complete papilla fill** without unsightly 'black triangles';
- **Gingival aesthetic line (GAL)** – gingival contour progression from central incisor to canine:
  Class I – GAL angle is 45–90°, lateral incisor is touching or below (1–2 mm) GAL;
  Class II – GAL angle is 45–90°, lateral incisor is above (1–2 mm) GAL, and its mesial aspect overlaps the distal aspect of the central incisor;
  Class III – GAL angle is 90° and the canine, lateral and central incisors all lie below GAL;
  Class IV – the gingival contour cannot be assigned to any of the above three classes.

Key points

- Anterior dental aesthetics is primarily concerned with the maxillary anterior six teeth.
- Aesthetic analysis is expedited by sequentially analysing the facial, dentofacial, dental and gingival perspectives.

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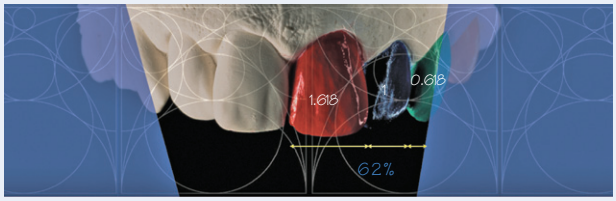
24 Anterior dental aesthetics: theories

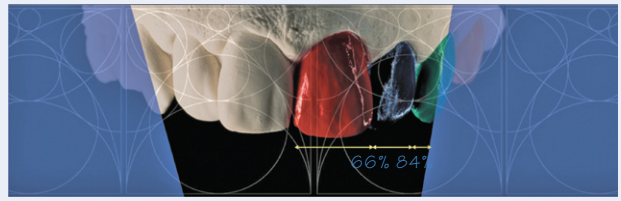
GEOMETRIC THEORIES



LOMBARDI 1973 — The repeated width proportion of anterior six teeth is in the Golden Proportion viewed from the frontal aspect

Progressing distally, the distal tooth is 62% of the immediate mesial tooth

Golden Proportion

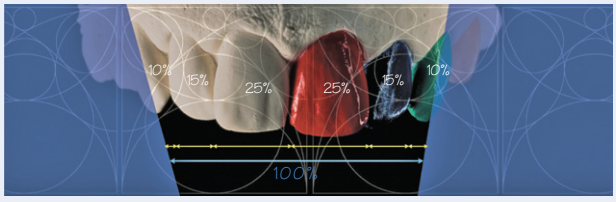


PRESTON 1993 — The repeated width proportion of each tooth is not identical

Progression from central to lateral incisor is 66%

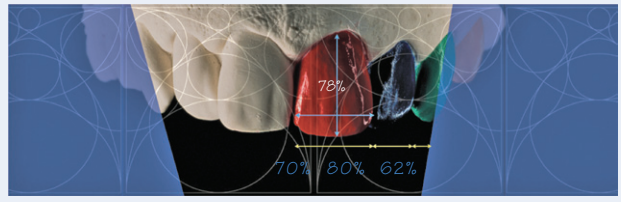
Progression from lateral incisor to canine is 84%

Natural Proportion



SNOW 1999 — The width of individual teeth is a percentage of the total width of the anterior six teeth

Golden Percentage



WARD 2001 — **Consistent repeated ratios are more important than a specific ratio**

For average tooth dimension of 78% (w/l ratio of 0.78), the recommended RED is 70%

For short teeth, 80% RED, and tall teeth a 62% RED (or the Golden Proportion)

RED Proportion

PSYCHOLOGICAL THEORIES

Full, voluptuous lips equating to large, round teeth

Thin, emaciated lips equating to slender, delicate teeth

PERCEPTION THEORIES

Aesthetic anomaly	Ideal	Tolerance
Smile arc (convexity)	2.7 mm	1.2 mm (3s) to 2.7 mm(7s)
Overbite	2.7 mm	5.7 mm
Maxillary central-to-incisal step	1.4 mm	2.9 mm
Bilateral negative space	16% of smile	8% to 22%
Positive canine or molar torque	None	Irrelevant
Maxillary gingival display	2.1 mm	+0.4 mm to –3.6 mm

Aesthetic anomaly	Ideal	Tolerance
Central incisor gingival discrepancy	0 mm	2 mm
Lateral incisor gingival height	– 0.4 mm	+ 1.2 mm to –2.9 mm
Width of lateral-to-central incisor	78%	45%
Discrepancy dental / facial midline	0 mm	2.9 mm
Discrepancy upper / lower midline	0 mm	2.9 mm
Occlusal plane cant	0 mm	3 mm (or 4°)

Degree of tolerance by laypersons for various aesthetic anomalies (after Ker et al., *JADA* 2008; 139: 1318–27)

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The search for a **magic formula** to quantify **beauty** has preoccupied artists, scientist and philosophers for over 5000 years. Yet, to date, there is no formula, law or dictum available that can decisively define the essence of beauty. Many hypotheses, opinions and ideas abound, which can broadly be categorised as **geometric**, **psychological** and **perceptual** theories.

Genesis of beauty

One of the earliest attempts to analyse beauty was by the ancient Egyptians around 3000 BC. The mathematicians of the time realised the importance of proportion for creating aesthetically pleasing objects. The idea of the **Egyptian triangle** was extensively used in arts and crafts, and as an architectural template for building the famous sphinxes and pyramids of Egypt.

The first person to postulate a mathematical formula for analysing beauty was **Pythagorus in 530 BC** with the concept of the **golden number**, **Φ** (1.618), and its reciprocal (1/1.618 = 0.618), the **golden proportion (GP)**. The significance of the GP is its prevalence in inanimate objects and animate beings. Items perceived as beautiful can be shown to have proportions that are in the GP. Plato, Aristotle, Euclid and others have emphasised the relevance of proportion in aesthetic appraisal.

Geometric theories

The concept of **proportion** and **form** has been the basis for many **geometric theories** in aesthetic dentistry. Below are some of the authors who have proposed mathematical guidelines for aesthetics of the maxillary anterior sextant:

- **Williams** (1914) – classified tooth shape as square, tapering or ovoid;
- **Lombardi** (1973) – first person to propose that the width progression of the maxillary anterior six teeth, **viewed from the frontal aspect**, can be related to the GP;
- **Preston** (1993) – disputed the GP and proposed the **natural proportion** for the width progression from the central to lateral to canine;
- **Gillen** (1994) – dispelled the myth of the GP for the maxillary anterior teeth;
- **Snow** (1999) – proposed that the anterior six maxillary teeth are in the **golden percentage**;
- **Ward** (2001) – emphasised that a specific ratio is irrelevant, and proposed a fixed **recurring esthetic dimension (RED)** for the anterior six teeth;
- **Radlinsky** (2009) – coined the **golden coefficients** for the curvature of the maxillary arch.

All the above theories have been invalidated by subsequent studies, and none is unequivocally prevalent in the maxillary anterior dentition, particularly the GP, which has been ubiquitously quoted in the dental literature. Nowhere is the saying '**A lie told often enough becomes truth**' (Vladimir Lenin) more appropriate than with the GP. Many researchers have concluded that the **GP is only present in 10% of the population**, yet this pseudo-standard is the cornerstone (and excuse) for many so-called aesthetic dental 'makeovers'. Furthermore, the **difference in tooth widths** using various theories can be as little as **0.5 mm**, an amount barely perceptible at close distance, let alone at a social viewing distance.

Psychological theories

Linking psychology with tooth form, contour and colour has also been the subject of numerous studies:

- **White** (1874) – coined the '**temperamental theory**', correlating tooth differences with an individual's disposition;
- **Frush and Fisher** (1958) – dynesthetic theory related the **sex**, **age and personality (SAP)** of a person with tooth form, contour and alignment of the anterior teeth;
- **Rufenacht** (1990) – **morphopsychological concept** relating facial and bodily features (morphology) with psychology as the determining factor for the shape and size of teeth;
- **Ahmad** (2001) – **synaesthetic perception**; emotional and subconscious decisions and choices take precedence over cognitive or mathematical rationality for aesthetic appraisal.

Most of the **psychological theories** are opinions, and cannot be confirmed or refuted by rigid scientific analysis. However, science cannot explain everything, and emotional and psychological factors are relevant because they account for patients' intangible desires and wishes. For this reason, the patient's input should be incorporated into every treatment plan involving aesthetic dental care.

Perception theories

Perception theories concentrate on what is perceived, both by the providers (dentists, ceramists) and end users (patients). The **salient difference between psychological and perception theories** is that the former concern '**the way we see ourselves**', while the latter concern '**the way others see us**'. Perceptual theories are currently becoming popular increasingly for aesthetic analysis and assessing the outcome of aesthetic treatment. Recent publications include:

- **Kokich** (1999) – first study using image manipulation to assess smile attractiveness, concluding that laypersons are less discriminating than dentists and orthodontists regarding aesthetic aberrations;
- **Pinho** (2007) – concurred that perception between dentists and laypeople vary enormously;
- **Ker** (2008) – comprehensive survey of laypersons' perceptions of aesthetic anomalies.

Perception theories gauge response from patients (and the dental team) and are extremely valuable for treatment planning, especially for preventing overtreatment. Furthermore, since patients are oblivious to minor aesthetic aberrations, it is the duty of dental professionals not to **unnecessarily sensitise** their patients or 'manufacture' dental conditions requiring interventional aesthetic therapy. However, the sample population for many of these surveys is small, specific to countries and cultures. Therefore, the findings cannot be applied to all populations or to every individual.

Key points

- There are no magic formulas, no magic numbers, no Holy Grail and no Da Vinci Code for evaluating or creating beauty.
- Geometric theories are a framework, not a formula.
- Psychological theories are pragmatic, not dogmatic.
- Perception theories are subjective, not objective.

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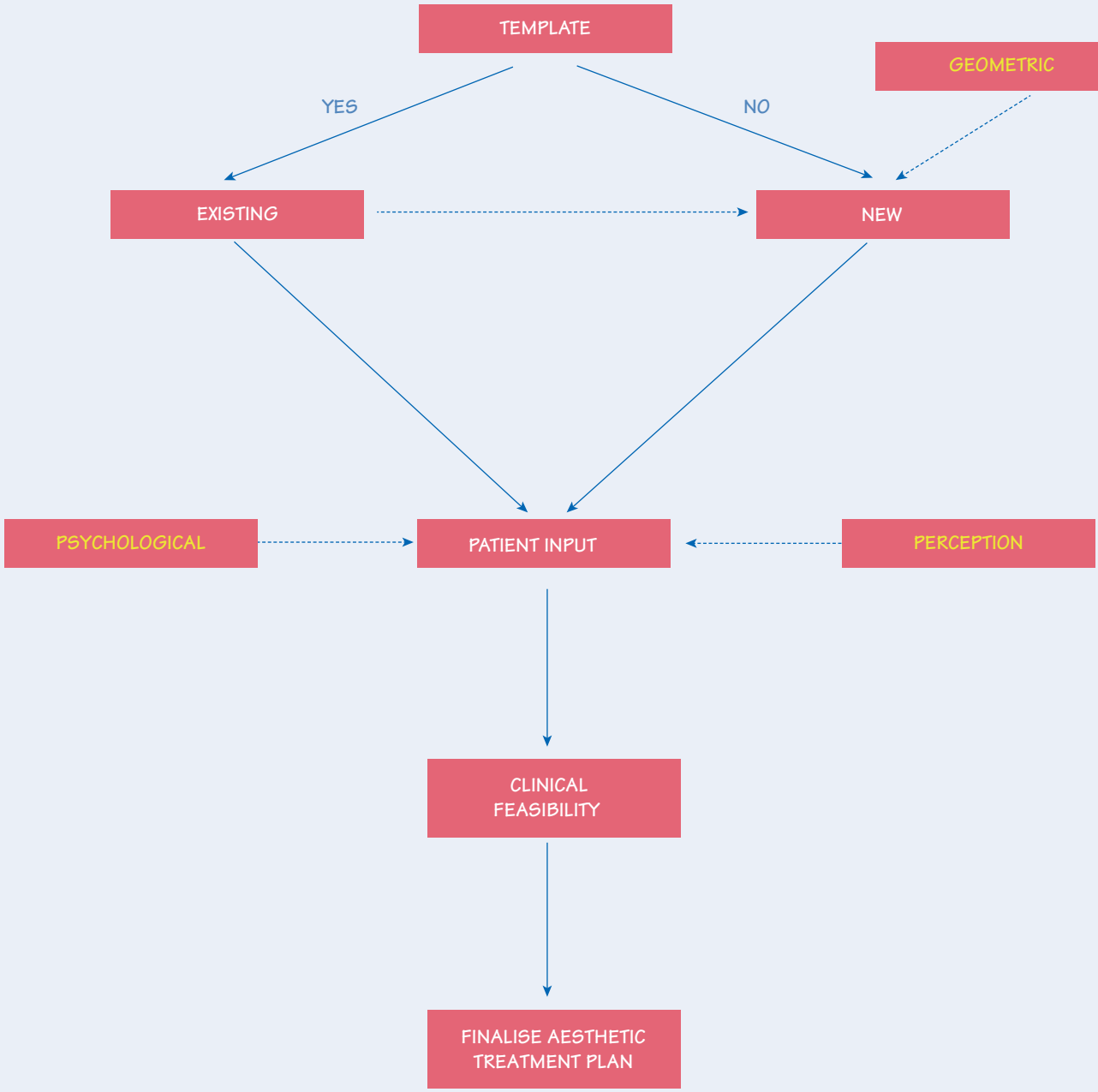
25 Anterior dental aesthetics: guidelines



Schematic and sequential guidelines for aesthetic treatment planning

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There are **numerous theories** regarding **dental aesthetics**, broadly categorised into **geometric**, **psychological** and **perceptual**. No single theory adequately explains the aesthetics of the maxillary anterior six teeth, or can be utilised to prescribe a definitive treatment plan. In reality **all theories can be synergistically used** to **analyse** and **finalise** anterior dental aesthetics.

General guidelines

Before proposing schematic guidelines for dental aesthetics, it is important to **establish principles** for treatment planning of aesthetic cases:

- At present, there are no **generally accepted objective standards** for **designing smiles**;
- Dental aesthetics **cannot be determined or analysed using a single parameter**;
- **Avoid sensitising patients** to minor aesthetic anomalies, which they would normally **accept** or otherwise **ignore**;
- **Discourage sensitising patients** to minor aesthetic anomalies based on media or peer pressure and social trends;
- The **culture of dissatisfaction marketing** for sensitising patients should be discouraged;
- Adopt a **minimally invasive** approach for resolving unacceptable dental aesthetics;
- Creating **diversity** in the maxillary anterior sextant is the **key to individuality**.

Template

The **starting point** for a dental aesthetics prescription is establishing a **template**, which can either be **existing** or **new**.

An **existing** template is the existing dentition, and the proposed aesthetic changes are designed to integrate within this framework. This ensures a **minimally invasive** approach, and avoids unnecessary overtreatment. If the anterior sextant is edentulous, or requires extensive alterations, one or more of the **geometric theories** can be used as a starting point for creating a **new** template. For example, if there is extensive crowding, misalignment or diastemata, a new working template is designed by simulations, e.g. diagnostic wax-up or intra-oral mock-ups. The **choice of which geometric theory to use is empirical**; often the **difference** in tooth widths between these theories can be as little as **0.5 mm**. However, the following aspects should be incorporated into a template:

- The **overall symmetry and balance** of the dento-facial complex is the salient factor for an aesthetically pleasing smile, rather than individual or localised items;
- The **average w/l ratio** of the maxillary teeth is **0.78 or 78%**;
- The **central incisors are dominant**;
- The average maxillary **tooth display** during a relaxed smile is **75%**;
- **No specific ratio for repeated proportions** is applicable to all individuals;
- **Smile arc (line)** is parallel to curvature of the mandibular lip during a relaxed smile;
- Acceptable maxillary **gingival display** during a relaxed smile is approximately 3 mm, thereby avoiding a 'gummy' smile.

Patient input

After defining a **working template**, either **existing or new**, the next stage is **modification of the template** by the patient's input. The patient's wishes are predominantly related to psychological and perceptual theories:

- The patient's input is essential **for a successful aesthetic treatment** outcome;
- The **patient's persona** is moulded by intellect, culture, social interaction and economic status;
- **Women** are usually more **intuitive and emotional** than **men**, and therefore make a more critical judgement about beauty and self-appearance.

The second aspect regarding the patient's input is **perception**. If an aesthetic aberration is **unnoticed** or the **patient is oblivious** to its presence, is it justifiable to correct it? Furthermore, many patients accept gross aesthetic abnormalities, and have little desire to make any changes. In both circumstances, **coercive sensitisation** to these irregularities that do not compromise health or function is counterproductive, and at times unethical. In addition, aesthetic anomalies are more apparent to the **trained eye** of a dentist than that of a layperson, whose **naiveté is often a blessing**. Lastly, most perception theories are based on **frontal view assessments** and **oblique** (profile), and **dynamic visualisations** require further research.

Clinical feasibility

The last stage of aesthetic treatment planning is assessing whether the **patient's wishes** are **clinically feasible**, and if they can be incorporated into the patient's prevailing clinical scenario. For example, if **tooth wear** has resulted in minimal space for restorative materials due to **alveolar compensation**, it is futile to provide restorations before creating space by the use of orthodontic appliances.

Another example is conceding to patients' wishes for **irreversible procedures** that may compromise dental health in the future, for example, providing **elective cosmetic treatment** entailing destruction of healthy teeth for the sake of vanity. Many so-called 'cosmetic makeover' procedures are questionable, ephemeral and possibly unethical.

Finally, science is dogmatic with little leeway, while art is nebulous, open to interpretation. Since aesthetics is an art, not a science, the scientific community is probably wasting its time trying to quantify rules and principles to decipher this entity. Hence, to date, all attempts over the last 5000 years to apply scientific rules and guidelines have failed to determine rigid principles for dental aesthetics. Aesthetic objectivity still remains an elusive goal, and perhaps one that may never be reached.

Key points

- No objective rules exist for analysing or prescribing dental aesthetics.
- The best guidelines for aesthetic treatment planning are adopting a minimally invasive approach, combining the available theories, i.e. geometric, psychological and perceptual.
- Patient participation is essential for successful outcome of an aesthetic treatment plan.

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26 Anterior dental aesthetics: bleaching

Preoperative

Tray with 10% or 35% carbamide peroxide

Postoperative

Preoperative

Intracoronal 35% carbamide peroxide

Postoperative

TECHNIQUES

VITAL
In office and at home

NON-VITAL
Walking bleaching

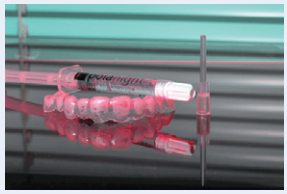
BLEACHING

MECHANISM
- Erosive
- Abrasive
- Oxidation

PRECAUTIONS
- Tooth protection
- Gingival protection

SIDE EFFECTS
- Sensitivity or altered enamel morphology
- Shade rebound
- Reduced enamel microhardness
- Reduced dentine bond strength
- Increased microleakage of existing restorations
- Root resorption or periradicular necrosis
- Reduced fracture strength

Bleaching tray


Bleaching agents

Light-activated units

Before restorations (pre-bleach)

Before restorations (post-bleach)

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Dental bleaching is an effective, economical and **minimally invasive** approach to whitening discoloured teeth. Since its introduction two decades ago by Haywood and Haymann, the **at-home** technique has proved a successful treatment modality for improving unsightly stained teeth. Bleaching is also **therapeutic for periodontal health** and favours maintenance of oral hygiene. Furthermore, the **transient irritation of soft and hard tissues** is innocuous and reversible.

Mechanism

Whitening teeth is achieved by any one of **three processes**, i.e. **erosive**, **abrasive** and **oxidation**. The most popular method is oxidation since erosion and abrasion potentially damage hard tissues by irreversibly altering tooth morphology. Furthermore, excessive enamel loss is counterproductive for tooth whitening, since it allows visibility of the darker underlying dentine.

The **oxidation process** uses bleaching chemicals that penetrate the interprismatic enamel substrate and convert the pigmented carbon rings to lighter carbon chains. The higher the concentration of the bleaching agent the greater and more rapid the effect. This process **alters enamel micromorphology**, affecting both the organic and inorganic phase of the hard tissue. The negative effect of oxidation is that bleaching chemicals, with a low pH, demineralise enamel. However, the effect is usually transient, since **calcium in the saliva** and use of **fluoride dentifrices** reverse the effect by remineralisation of the enamel surface layer.

Techniques

The commonly used bleaching agents are **carbamide peroxide** (urea peroxide) in concentrations ranging from 1% to 45%, **hydrogen peroxide** (3% to 50%) and **sodium perborate**. These agents are available as gels, varnishes, mouthwashes and toothpastes. The **concentration** of the bleaching agent determines the duration of treatment. A **high concentration** results in rapid whitening in a shorter time, while lower concentrations require longer to take effect. There are two main methods for bleaching, either **in office** or **at home** (with professional supervision). The latter can be combined with an in-office 'jump start', followed by slower completion at home.

Vital bleaching can be prescribed **alone** for whitening teeth or can be **part of a global aesthetic treatment plan**, e.g. before veneers, crowns or tooth-coloured 'white' fillings. In isolation, bleaching can be used to alter colour for teeth displaying **yellow**, **brown/grey** or **tetracycline intrinsic stains**. The technique involves fabricating carefully adapted **custom-made plastic trays** using a heat/vacuum tray-forming machine. The trays are filled with the chosen agent and placed over the teeth for specified durations, followed by brushing with a toothpaste containing a high concentration of sodium fluoride (2800 ppm). The duration of treatment depends on the extent of discolouration; the bleaching process can take **2–6 weeks** at home if the trays are worn for **2–3 hours per day** using **10% carbamide peroxide**. The **efficacy** is 2–10 shades of colour modification on the Vita Classic shade guide arranged in value order. However, there is a 1–2 shade **rebound** after 2–4 weeks. Therefore, it is advisable to wait before proceeding with new aesthetic restorations so that the latter can be matched to the stabilised colour of the bleached teeth. For **severe stains**, e.g. intense tetracycline staining, whitening may take **6–12 months**. During the bleaching process, it is essential to provide **professional supervision** throughout treatment, and monitor changes with photographs and reference shade tab guides.

Non-vital bleaching is a third option used to lighten **endodontically treated teeth**, often referred to as intracoronal or '**walking bleaching**'. Before starting, it is essential to ensure that the existing root filling has a **satisfactory apical seal** to prevent leaching of the bleaching agents into the **periradicular areas**, and causing **root absorption**. The technique involves placing bleaching agents into the pulp chamber and hermetically sealing the cavity with either glass ionomer or a resin-based composite filling to prevent microleakage and percolation of bacteria.

Light-activated bleaching involves using bleaching chemicals containing **carotene** to accelerate the breakdown of the active ingredients when exposed to high-intensity **light** or **lasers**. However, light alone has no effect on tooth whitening, but the heat generated by lights may accelerate the whitening effects of bleaching chemicals. Furthermore, **heat** can **dehydrate teeth**, leading to greater **postoperative sensitivity**.

Precautions

While effective and simple, certain conditions are required before considering bleaching:

- **Tooth protection** – pre-treatment **sensitive areas**, e.g. cervical or abfraction lesions, should be sealed with glass ionomer. Also, bleaching areas of **gross tooth wear** with exposed dentine may cause further dentine erosion. Finally, for **pronounced fluorosis** or developmental banding, micro-abrasion may be indicated to avoid uneven bleaching;
- **Gingival protection** – rubber dam or other gingival barriers are essential when using in-office high-concentration bleaching gels.

Side-effects

Some side-effects of bleaching include:

- **Sensitivity** (tooth and gingival), particularly with higher concentrations of bleaching agent, but is mitigated by **remineralisation** with fluoride, potassium nitrate or sodium citrate;
- **Reduced enamel microhardness** (outer 25 µm surface) immediately after bleaching, usually reversed by saliva remineralisation in 3–4 weeks;
- **Reduced dentine bond strengths** (especially using sodium perborate), but there is little change in enamel bond strength 1 week post-bleaching;
- **Increased microleakage** at the interface between dentine and restorative material, but margins on enamel remain intact;
- **Effects of bleaching on restorative materials**, especially composites and glass ionomer fillings, which may cause existing fillings to become more conspicuous;
- Excessive bleaching with high concentrations may result in **chemical and morphological changes in enamel structure** leading to porosity, pitting, reduced fracture strength, erosion or lesions emulating initial caries.

Key points

- Bleaching is a simple and effective method for whitening teeth.
- Professional supervision and monitoring are essential to enhance treatment and mitigate side effects.

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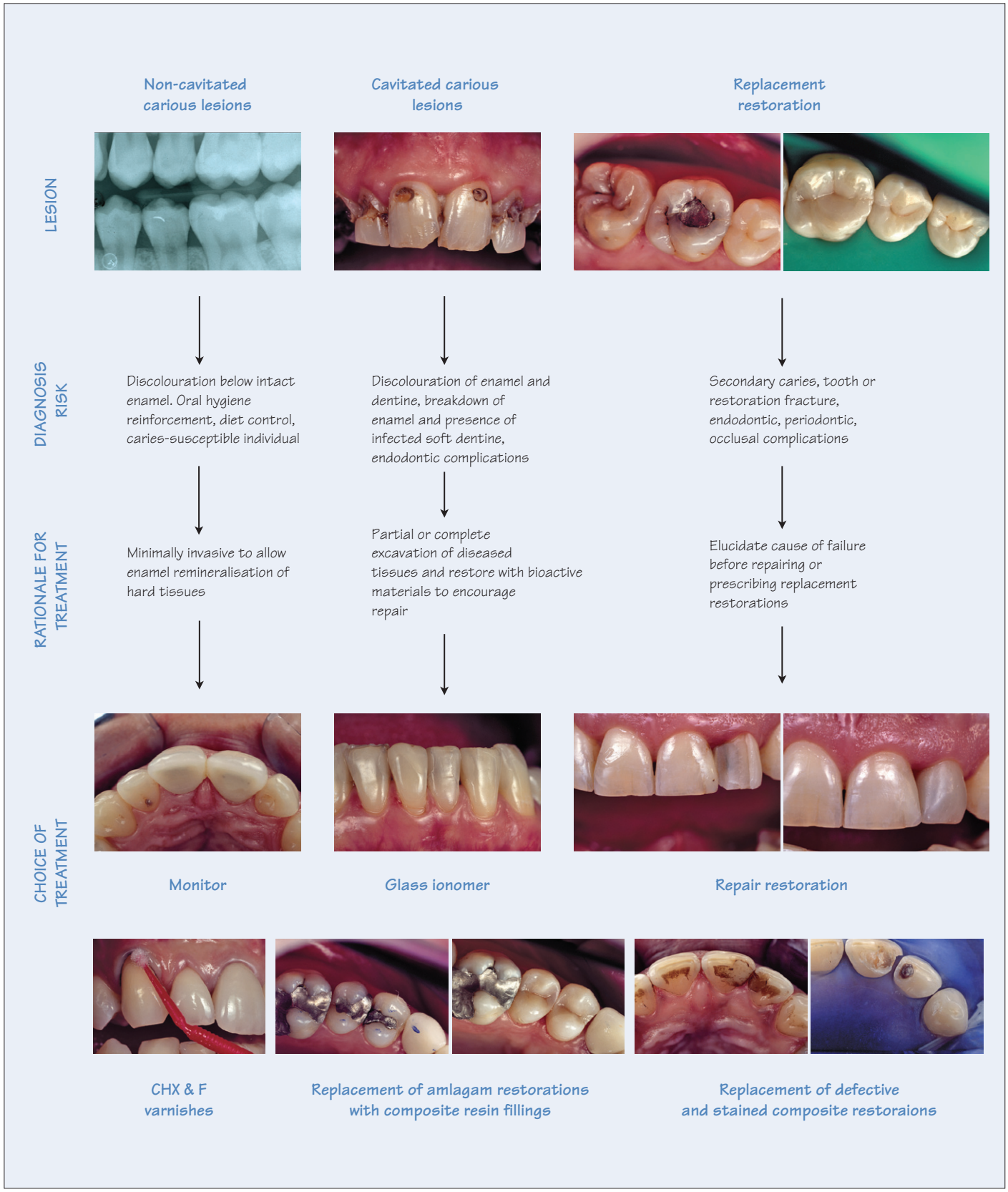
27 Choice of intracoronal restorations



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Intracoronal restorations are defined as those surrounded by one or more natural tooth surface(s) and can broadly be categorised according to **Black's cavity classification**; classes I, II, III, IV and V, and the newly added class VI.

Treatment for **intracoronal lesions** depends on a variety of factors, and for optimal **clinical decision-making**, it is necessary to accurately **diagnose** pathology, determine **aetiology**, identify **risk factors** and assess **prognosis** for various **treatment options**.

Non-cavitated carious lesions

Current research has highlight the ability for enamel to **remineralise** following carious attack. Therefore, a **non-cavitated carious lesion** extending into dentine, with appropriate treatment, has the potential to be arrested by **remineralisation** of the demineralised enamel hard tissues. The factors to consider for non-cavitated lesions are:

- **Aetiology** – cariogenic bacteria;
- **Clinical presentation** – discolouration below surface of an unrestored tooth; caution is necessary when using sharp probes, in order to avoid piecing the delicate demineralised surface enamel;
- **Symptoms** – none or sporadic sensitivity;
- **Risk assessment** – patients with poor oral hygiene, inadequate diet control, or individuals with high caries susceptibility require restorative intervention;
- **Treatment options** – minimally invasive, monitor for low-risk patients, or restore for high-risk patients;
- **Type of restoration** – chlorhexidine (CHX) and fluoride (F) varnishes, fissure sealing, direct restorations;
- **Choice of restorative materials** – bioactive restorative materials (glass ionomers, resin-based composites), or amalgam;
- **Prognosis/outcome:**
  a) Halted carious lesion with or without remineralisation of enamel – monitor with periodic application of varnishes and/or fissure sealants;
  b) Reparative 'healing' with bioactive restorative materials – monitor;
  c) Progression to cavitated carious lesions – intervention with direct fillings.

Cavitated carious lesions

Once cavitation is evident, restorative intervention is necessary to prevent progression of the lesion. The factors to consider for cavitated lesions are:

- **Aetiology** – cariogenic bacteria;
- **Clinical presentation** – fractured and discoloured enamel with underlying **carious**, **discoloured soft dentine**, affecting any surface, or a combination of surfaces. The morphology and depth of the lesion depends on the extent of disease progression. Health, aesthetics and function may be compromised and endodontic complications may ensue;
- **Symptoms** – sensitivity, pain, abscesses;
- **Risk assessment** – assess oral hygiene, diet control, caries susceptibility, endodontic involvement and periodontal and occlusal factors;
- **Treatment options** – **minimally invasive** (partial or minimal caries excavation and restoration) or **conventional** (complete caries excavation and restoration);
- **Type of restoration** – **direct restorations** (using Black's classification to define location of lesions). For larger coronal defects and destruction, **indirect** inlays or full coverage may be considered;
- **Choice of restorative material** – bioactive restorative materials (glass ionomers, resin-based composites), amalgam, ceramic, cast gold or metal fused to porcelain;
- **Prognosis/outcome:**
  a) Reparative 'healing' with bioactive restorative materials – monitor;
  b) Tooth or restorative material fractures – cuspal or full coverage;
  c) Endodontic involvement – root canal therapy.

Replacement restorations

Replacement of **failed or defective restorations** constitutes about 60% of operative dentistry. Before considering a new restoration, it is essential to elucidate the **cause of failure**, promote **preventive measures** and provide an appropriate restoration to **prevent future eventualities**. The factors to consider for replacement restorations are:

- **Aetiology** – hostile oral conditions such as cariogenic bacteria, occlusal loads, fatigue, temperature changes, aqueous environment, poor clinical technique or incorrect material selection (e.g. microleakage, restorative material failure);
- **Clinical presentation** – recurrent or secondary caries. It is worth remembering that a **marginal discrepancy** or **gap** is **not necessarily a predictor of secondary caries** or disease process, fractured tooth or restorative material, poor aesthetics, pulpitis, periapical lesions, periodontal or occlusal complications;
- **Symptoms** – pain, abscesses or soft tissue laceration due to sharp edges of fractured teeth/restorations;
- **Risk assessment** – assess oral hygiene, diet control, caries susceptibility, endodontic, periodontal and occlusal factors, poor clinical technique;
- **Treatment options** – **repair vs replace benefits**. For **small restorations**, a '**like for like**' approach may be all that is required, provided that the cause of failure is deciphered and rectified. For **larger failed restorations**, it may be necessary to prescribe an alternative type of restoration, or alternative material, or both;
- **Type of restoration** – direct restorations (using Black's classification to define location of lesions). For large restorations with loss of coronal tissue, the options are indirect inlays, onlays or full coverage crowns;
- **Choice of restorative material** – bioactive restorative materials (glass ionomers, resin-based composites), amalgam, ceramic, cast gold or metal fused to porcelain;
- **Prognosis/outcome:**
  a) Reparative 'healing' with bioactive restorative materials – monitor;
  b) Tooth or restorative material fractures – indirect inlay;
  c) Endodontic involvement – root canal therapy;
  Extensive coronal tissue loss incapable of supporting an intracoronal restoration – extracoronal indirect full coverage.

Key points

- The choice of intracoronal restoration depends on accurate diagnosis.
- Both non-cavitated and cavitated lesions should be treated with a minimally invasive approach and periodically monitored.
- It is essential to elucidate the cause of failure before prescribing a replacement restoration.

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28 Choice of materials for direct restorations

Before After

Replacement of defective composite fillings

Before After

Replacement of defective amlagam fillings

Staining Wear

Stained and worn restorations

COMPOSITES

Advantages

Highly aesthetic
Large varieties of materials for varying clinical situations
Minimally invasive cavities
Bond to tooth structure with DBA
Acceptable physical and mechanical properties
Reinforce tooth/restoration complex
Light and chemically cured
Bioactive
Suitable for direct restorations, e.g. pit & fissure sealing, class I, II, III, IV, V, VI, tunnel cavities, aesthetic masking of discoloured teeth, and indirect inlays and veneers

Disadvantages

Polymerisation shrinkage and stresses
Technique sensitive and protracted procedures
Microleakage
Shorter survival rate in stress-bearing areas compared to amalgam
Water adsorption
Wear
Discolouration
Costly; increased material costs and longer clinical time

AMALGAM

Advantages

Established clinical history
Long-term survival rate
Suitable for large Class I, II
Forgiving technique
Economical
Micro-mechanical retention with DBA

Disadvantages

Poor aesthetics
Corrosive byproducts
Mercury exposure
Invasive cavities

GLASS IONOMERS

Advantages

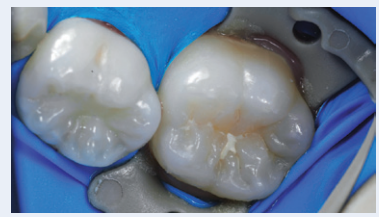
Chemical adhesion to tooth
Bioactive
Combination materials with resin-composites to improve properties
Suitable for pulp capping, luting agents, class V and fillings in deciduous teeth

Disadvantages

Poor mechanical properties
Poor survival rate compared to amalgam
Crack formation when exposed to oral environment

10-year-old filling

Failed filling



Deciduous teeth

Cervical fillings

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Material selection for intracoronal direct restorations is a daunting task. At present, there is no material on the market that is a true substitute for dentine and enamel, and a compromise is usually necessary depending on the prevailing clinical situation. Most intracoronal cavities are restored using a **direct technique**. However, **inlays** are also possible using an **indirect technique**. The **performance** and **survival** of any direct restoration is **multi-factorial**, depending on the **location of the tooth**, **type of tooth**, **restoration design** and **size**, number of **surfaces involved**, **operator factors** (experience, dexterity and technique), **patient factors** (age, attitude to dental care, oral hygiene) and the **choice of material**. The main reasons cited for **failure** are **secondary caries**, **fractures**, **discolouration**, **marginal discrepancies**, **wear** or **endodontic involvement**.

Palliative dressings

The most popular temporary palliative dressing is **zinc oxide eugenol**. Zinc oxide powder is mixed with eugenol liquid to form a condensable putty. Care is necessary if the definitive filling is resin-based since **eugenol retards the setting reaction of most resin-based composites**.

Silver mercury amalgam

The use of silver mercury amalgam dates back to the beginning of the last century when Black first described his classification of dental cavities. Dental amalgam is a mixture of **silver alloy powder** mixed with **mercury**, creating a condensible slurry that solidifies at intra-oral temperature. Amalgam, unlike composites, is a relatively **forgiving material**, not dependent on stringent clinical protocols. Its use is still ubiquitous, with **longer survival rates** (compared to composites) for large direct restorations in **posterior**, **load-bearing teeth**. However, recent concern about **low-level mercury exposure** is scientifically unfounded, but remains contentious for many patients. Some European countries have **banned amalgam** use altogether, while others have contraindicated its use in **susceptible patients**, e.g. females of child-bearing age. Other **disadvantages** include the need to remove excess tooth substrate when creating **undercuts** (but **micro-mechanical adhesion** is possible using dentine bonding agents – **DBA**), leaching into enamel/dentine with subsequent **tooth discolouration**, **amalgam tattoos** on the oral mucosa, and **environmental waste** concerns.

Resin-based composites

Resin-based composite fillings are rapidly becoming the **first choice** for direct intracoronal restorations. A **composite filling** material is a combination of **organic resin** (e.g. Bis-GMA, urethane dimethacrylate or TEGMA) and an **inorganic filler** (e.g. quartz, glass or silica). The **size** and percentage of **filler loading** determines the properties of the final material. Several varieties are available:

- **Conventional** composites (quartz, glass): filler particle size = 1–50 µm;
- **Microfilled** composites (silica): filler particle size = 0.01–0.1 µm;
- **Hybrid composites** (quartz, glass and silica): 1–50 µm (75%) and 0.04 µm (8%) i.e. total filler content of 83%, which can be increased to 90%;
- **Nano-composites** – similar properties to microfilled and hybrid composites but with smaller **nano-particle fillers**;
- **Flowable** – reduced filler content, reduced viscosity, reduced polymerisation stresses but increased shock-absorbing capabilities;
- **Bulk-fill composites** – can be cured to a depth of 5 mm, e.g. SonicFill (KerrHawe SA, Switzerland), SDR (Dentsply, Germany).

The major **advantages** of composites are the colour, similar to natural teeth, the ability to bond to tooth structure (with DBAs), minimally invasive cavity preparation, similar thermal diffusivity to dentine (acting as thermal insulators), acceptable mechanical properties, reinforcement of the restoration–tooth complex, command setting with curing lights, and bioactivity. A **bioactive** material is one that forms crystalline deposits at the tooth interface, thereby improving marginal adaptation. Composites are indicated for most **direct restorations** as well as indirect **inlays**. The major **disadvantage** of resin-based composites is **polymerisation shrinkage** (1.5–3%) and **stresses** during the setting phase which result in microleakage, secondary caries, marginal staining, postoperative sensitivity and cuspal fractures. Polymerisation shrinkage can be mitigated by altering the **material properties** (e.g. higher filler content, pre-polymerisation) and **clinical techniques** (e.g. bonding to enamel rather than dentine, cavity design with low C-factors, incremental placement and varying curing light modes). Finally, long-term water absorption leads to porosity and accelerated wear.

Glass ionomers

The distinguishing feature of glass ionomers is their ability to **chemically bond** to tooth surfaces by chelation of the calcium ions within the hydroxyapatite with the polyacid in the material. Another benefit is enhanced **bioactivity**, especially with the addition of fluoride. They are therefore indicated for **pulp capping**, **linings**, **luting cements**, **class V cavities** and **fillings in deciduous teeth**. The **drawbacks** of glass ionomers are poor mechanical properties, water adsorption and crack formation.

Combination materials

Several combination materials are available, exploiting the beneficial properties of composites and glass ionomers. For example, **resin-modified glass ionomers** most closely resemble conventional glass ionomers, offering improved adhesion to tooth, while **compomers (polyacid-modified composite resins)** have a closer relationship to composites, with improved mechanical properties. Another combination of resin and glass ionomers is the **giomer**, with enhanced fluoride-releasing properties by incorporation of a pre-reacted glass (PRG). A recent development is using **Ormocer®** technology for direct restoratives. The latter exhibit excellent wear resistance, but poor polishability. The latest materials to emerge are the **compobonds** combining a resin-based composite with a DBA. The first of these materials is a **self-adhesive flowable composite**, Vertise Flow (KerrHawe SA, Switzerland) obviating the need to use a DBA before placing the composite filling.

Key points

- Irrespective of mercury exposure concerns, amalgam still has good survival rates for large cavities in posterior teeth.
- Although technique sensitive, resin-based composites are becoming the first choice for direct restorations.
- Glass ionomers offer chemical adhesion to tooth, and are useful for pulp capping, luting agents, and fillings in deciduous teeth.
- Numerous combination materials are available, exploiting the respective benefits of different materials.

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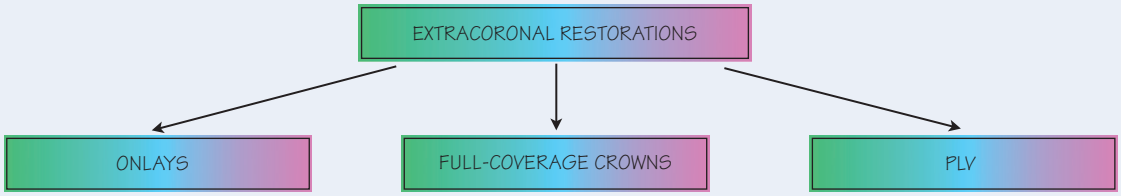
29 Choice of extracoronal restorations

Extracoronal restorations



Survival rates

Type of restoration	Survival rate (%)	Period (years)
Inlay and onlays	95	7–10
Porcelain fused to metal (PFM)	> 95	10
Porcelain laminate veneer (PLV)	> 94	12
Leucite-reinforced pressed glass – IPS Empress® (anterior single unit)	> 95	11
Leucite-reinforced pressed glass – IPS Empress® (posterior single unit)	84	11
Lithium disilicate IPS Empress 2® (anterior and posterior single units)	> 95	5
Glass infiltration – In-Ceram® (anterior and posterior single units)	> 98	5
Polycrystalline alumina – Procera® (anterior single units)	> 99	7
Polycrystalline alumina – Procera® (posterior single units)	> 98	7
Zirconia (multiple unit fixed partial denture; FPD)	74	5

Clinical examples

Cavity size

When the width of an intracoronal cavity exceeds 1/2 the distance of the cusp tips, an onlay or crown is necessary

Cracked tooth

A symptomatic cracked tooth syndrome often required coverage of the offending cracked cusp(s)

Replacement crown

Defective crowns are a common reason for providing a superior fitting crown to prevent decay and maintain periodontal health

Discoloured cusps

Amalgam or metal corrosive byproducts of old restorations can result in unsightly appearance, requiring removal and coverage with an extracoronal restoration

Stained composites

Large, defective, failing, stained composites on anterior teeth are candidates for ceramic PLVs

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The transition between an **intracoronal** and an **extracoronal restoration** is based on the amount of remaining tooth substrate following removal of decay and/or existing restorations. If sufficient dentine and enamel are present, an **intracoronal restoration (direct or indirect)** is the first choice of treatment. With greater tooth loss, reduced retention, coronal destruction and mutilated anatomy, an **indirect extracoronal restoration** is superior for restoring morphology, function, aesthetics and durability. Essentially, extracoronal restorations are classified as **onlays**, **veneers** and **full-coverage crowns**. The distinction between an onlay or veneer and a **partial coverage crown** is nebulous, and various configurations have been proposed, e.g. ½, ¾, ⅞, etc. depending on the remaining tooth substrate and the type of restorative material used.

Decision-making rationale

Decision-making with the **informed consent** of the patient depends on the following criteria:

- **Minimal intervention** – retaining maximum tooth structure and respecting periodontal, occlusal and pulpal health;
- **Tooth integrity** – strength of remaining tooth structure, and performance and durability of the chosen restorative material;
- **Clinical feasibility** – access for facilitating preparation, placement, impressions and cementation;
- **Prognosis and survival rates** – resistant to wear, occlusal forces, fractures and ease of oral hygiene procedures;
- **Aesthetics** – location of tooth in mouth;
- **Cost** – use of a dental laboratory increases fees compared to a direct approach.

Decision making-guidelines

Below are indications for **indirect restorations**:

- **Cavity size** – for posterior teeth with defective old restorations, the criteria for replacement depend on the size of the cavity once the restoration and decay are removed. If the **occlusal width of the intracoronal preparation** is **greater than half the distance of the buccal and lingual cusp tips**, an extracoronal restoration should be considered. In these circumstances, an onlay or full-coverage crown is necessary to protect the thin cross-section and fragile cusps, and to increase the tooth's resistance to fracture;
- **Cracked tooth syndrome** – tooth fracture associated with pain on biting and sensitivity to sugary foods. Diagnosis is by trans-illumination from the buccal or lingual aspects to ascertain the location and depth of the fracture lines(s). **Horizontal fracture lines** usually result in breakage of the involved cusp. If pain persists, following tooth preparation and temporisation beyond the visible fracture line, endodontic therapy or extraction may be indicated;
- **Fractured cusps** – deep apical or subgingival fractures may necessitate endodontic treatment, e.g. crown lengthening before crowning;
- **Unsupported cusps** – if decay or existing restoration necessitates removal of all supporting dentine, the remaining unsupported enamel should be removed and incorporated into an onlay preparation;
- **Endodontically treated teeth** – more susceptible to fractures than vital teeth, since the former **lack proprioceptive response**. The treatment options depend on the size of the access cavity and existing restorations. If the access cavity and existing restoration are small, a direct composite is an ideal choice. However, for larger restorations, an onlay, reduced crown, conventional crown, or possibly an **endocrown** (gaining macromechanical retention from the pulp chamber of root-filled posterior teeth) should be considered;
- **Parafunctional habits** or **hard diet** – patients with bruxism or who eat hard food are candidates for cuspal coverage;
- **Discoloured cusps** – usually resulting from amalgam leakage byproducts, which are unsightly if visible during a smile may require removal and replacement with an onlay;
- **Hemisectioned teeth** – full coverage for splinting to adjacent teeth for stability;
- **Existing crown** requiring replacement due to fractured porcelain, colour mismatch, defective margins or gingival recession;
- **Short clinical crowns** – if the remaining tooth substrate is insufficient for an onlay, full coverage offers better retention;
- **Splinting teeth** – mobile teeth can be splinted using crowns, but this is a highly destructive and questionable modality. A less invasive option for symptomatic mobile teeth is splinting with orthodontic wire luted with a resin-based composite;
- **Fixed partial denture (FPD)** – either to close a space or to replace a failing FPD;
- **Implant-supported crowns** – both single and multiple splinted units;
- **Elective crowns** – if the patient declines orthodontic treatment to realign teeth, or to mask discolouration for improving aesthetics or to raise the occlusal vertical dimension (OVD). However, to provide crowns on vital teeth solely for aesthetic reasons is questionable practice.

Survival rates

Inlays and onlays can be fabricated from composite resin, ceramics and cast gold. The current trend is to use tooth-coloured restorations, which limits the restorative materials to composites or ceramics. **Unilayered** silica-based ceramics include feldspathic, leucite-reinforced pressed glass or lithium disilicate. Furthermore, the use of **CAD/CAM technology** has increased the popularity of these indirect restorations. Both inlays and onlays have a success rate of greater than **95% over 7–10 years**, and **bulk fracture** of the restoration is cited as the predominant reason for failure.

Porcelain laminate veneers (PLVs) are usually prescribed for **anterior teeth**, which require **superior aesthetic**, but have **low structural demands** (see Chapter 36).The most popular materials for PLVs are high glass content silica ceramics that can be adhesively bonded to the underlying tooth structure (preferably enamel). PLVs have shown to be extremely successful, with some studies reporting survival rates after **12 years of greater than 94%**.

Full coverage crowns can be fabricated using metal, porcelain fused to metal (PFM) or all-ceramic. The all-ceramic units are usually **bilayered** with a dense ceramic **core** for strength (e.g. glass-infiltrated and polycrystalline **alumina** or transformation-toughened polycrystalline **zirconia**) and a weaker veneering porcelain (e.g. **silica ceramics**) for aesthetics. All-ceramic units on anterior teeth have a higher success rate than on posterior teeth. The **overall survival rate is comparable to that for PFM crowns**; silica is better suited for anterior teeth, while alumina and zirconia are better for posterior teeth. Again, the main reason for failure is **catastrophic fracture** or **chipping of the veneering porcelain**.

Key points

- Extracoronal indirect restorations are indicated for compromised teeth with reduced tooth substrate.
- Choosing the type of extracoronal restoration depends on the clinical scenario and survival rates.
- The survival rate for indirect ceramic restorations is about 90% over 10 years and is comparable to that of PFM units.

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30 Cast metal alloys, titanium and resin-based composites

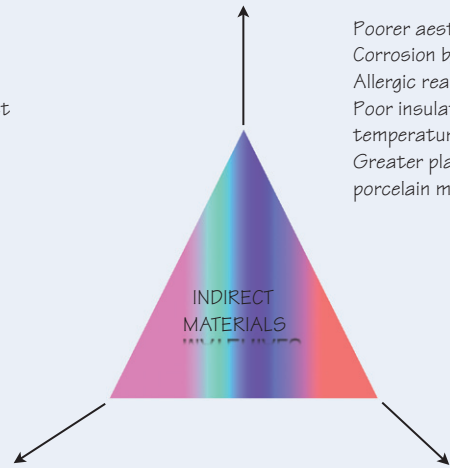
Cast metals

Advantages

Long-term successful clinical history
Established clinical and laboratory protocols
High strength and resistance to fracture
Versatility for fabricating a large variety of indirect restorations
Ability to fuse porcelain on metal substructure
Choice of strengths for varying occlusal demands
Ideal for long-span FPD on both natural and implant-supported abutments
Ability to solder units, e.g. post-ceramic soldering
Enhanced micromechanical adhesion using DBAs and self-adhesive resin cements
Reduced opposing tooth wear

Disadvantages

Poorer aesthetics compared to all-ceramic units
Corrosion byproducts
Allergic reactions to base metals
Poor insulators, resulting in transient sensitivity to temperature
Greater plaque accumulation compared to glazed porcelain margins of all-ceramic units



Titanium

Advantages

Highly biocompatible
Corrosion resistance
High strength and rigidity
Low density and weight
Withstands large temperature fluctuations
Lightweight prostheses
Laser welding of multiple units
Utilise CAD/CAM technology for milling frameworks

Disadvantages

High casting shrinkage
Technique-sensitive dental laboratory protocols
Expensive equipment for processing

Resin-based composites

Advantages

Aesthetic restorations
Improved aesthetic and mechanical properties compared to directly placed composites
Tight interproximal contacts
Excellent anatomical form
Precise marginal integrity
Improved surface texture
Reduced opposing tooth wear
Similar thermal expansion as natural tooth
Fibre reinforcement for increased strength
Good insulators
Reduced cost compared to cast metals and titanium

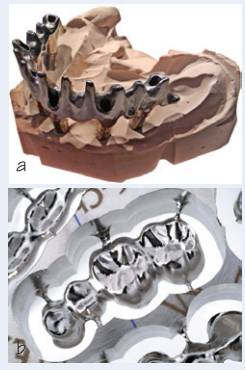
Disadvantages

Increased cost due to use of a dental laboratory, compared to direct restorations
Technique-sensitive, adhesive luting protocol
Weaker materials compared to cast metals and titanium

Comparison of MOE

Substrate	Modulus of elasticity (GPa)
Enamel	73
Dentine	19
Alveolar cortical bone	14
Alveolar trabecular bone	1.4
Resin-based luting agent	9
Resin-based composite filling material	20
Lithium disilicate ceramic core	102
Veneering fluorapatite porcelain	67
Zirconia core	210
Zirconia veneering porcelain	80
Cast gold alloys	80–100

Gold inlay



Titanium framework

Composite inlay

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Several **materials** are available for **indirect restorations** including **cast metal alloys**, **titanium**, **resin-based composites** and **ceramics**. Traditionally, metal alloys were the ideal choice for indirect restorations, but recent material advances are rapidly changing this paradigm, making composites and ceramics formidable contenders for clinical suitability and longevity. This chapter discusses cast metal alloys, titanium and resin-based composites, while Chapter 31 elaborates on ceramics.

The **success** and **longevity** of any restorative materials depends on:

- **Patient factors** – oral hygiene, patient constitution and medical history;
- **Material properties** – strength, wear, biocompatibility, marginal integrity, physical and chromatic stability, resilience for resisting occlusal forces and retaining anatomical form, and prevention of secondary caries;
- **Clinical technique** – material manipulation, placement and maintenance.

Strength of restorative materials

Ideally, a restorative material should mimic the physical, mechanical and optical properties of the tissue it is replacing. The **modulus of elasticity** (**MOE**) plays a pivotal role in determining the success or failure of a material, and the surrounding or underlying natural tooth substrate. Restorative materials with **similar MOE to dentine**, such as resin-based composites, absorb stresses, allowing dissipation by dentine, the periodontal ligament and surrounding alveolar bone. Conversely, rigid material with an **MOE similar to enamel**, such as ceramics, are more stress-resistant and transfer forces to the weaker material, i.e. dentine, making the tooth more susceptible to root fracture.

Cast metal alloys

The most frequently used cast metals in dentistry are **high noble content gold alloys**, which can be classified as:

Type I – low strength for small inlays and intraradicular posts;
Type II – medium strength for large inlays and onlays;
Type III – high strength, for full-coverage crowns and fixed partial dentures (FPD);
Type IV – extra high strength, for full-coverage crowns, FPD and denture frameworks.

The nobility of dental casting alloys usually depends on the **gold content**, which ranges from **60% to 75%**. For increasing strength, the amount of gold decreases and is replaced by other metals such as silver, copper, platinum, palladium and zinc. While hardness, MOE and tensile strength increase with decreasing gold content, **resistance to corrosion also decreases**. Recent concern about **palladium allergy**, especially among nickel allergy sufferers, has led to doubts about the use of palladium in dental prostheses.

Base metal alloys containing non-noble metals such as nickel, cobalt and chromium exhibit high strength (especially in thin cross-sections), are lighter in weight, and are indicated for crowns, bridges and partial denture frameworks. The disadvantages include allergy to nickel, greater rigidity compared to noble alloys, and therefore may result in fracture of the veneering porcelain in long-span bridges. Furthermore, adjustments to the metal substructure are more difficult.

Titanium

Titanium and **titanium alloys** are well established in the aerospace industry due to their favourable mechanical and physical properties. Titanium is mined as an oxide, but is refined to a metallic state using the **Kroll process**. Titanium is available in **four grades of pure titanium** or **three grades of titanium alloys** containing traces of aluminium, vanadium and iron. Its strength, rigidity and ductility are similar to that of other casting alloys used in dentistry.

Titanium is a highly reactive material that readily forms an **oxide layer** on its surface when exposed to oxygen. The oxide layer confers anticorrosive properties, and allows **bonding of fused porcelain** or **polymers** for aesthetic restorations. In addition, the surface can be sprayed with **apatite coatings** for implants to enhance **osseointegration**. The passivating oxide layer is also advantageous for **soft tissue attachment** around **titanium abutments** used to support the eventual dental prosthesis on subperiosteal implants. Developments in processing methods such as **lost-wax casting**, **CAD/CAM milling** and **electric discharge machining** have expanded its application in dentistry for **crowns** and **partial denture frameworks** for implant-supported prostheses. This is a promising development for the future, and titanium could challenge or replace conventional noble and base metal alloys for indirect restorations, especially in conjunction with CAD/CAM fabrication.

Resin-based composites

The **drawbacks** of **direct composite restorations** include poor wear resistance, chromatic instability, water adsorption and marginal discrepancies. Most of these problems are due to **polymerisation shrinkage, stresses** within the materials and **techniques** for **placement** and **polishing**. To overcome these deficiencies and improve clinical performance, **indirect composite restorations** have been developed. The main difference between direct and indirect composites is the method of polymerisation. With the former, photoactivation is used intra-orally to initiate the setting reaction. In the latter, special ovens are used to set the material by **light**, **heat and pressure**, which increases the **degree of conversion to 98%**, compared to **50–70% for direct composites**. Indirect processing **improves colour stability** and **mechanical properties** of the composite such as **hardness**, **tensile strength** and **flexural strength** and **reduces the stresses of polymerisation shrinkage**. Furthermore, extra-oral shaping of the restoration allows better **proximal contacts** and **occlusal morphology**. **Indications** for indirect composite restorations include inlays, onlays, veneers, crowns and **fibre-reinforced FPDs**, especially for patients who refuse intra-oral metal or have parafunctional activity. However, due to the relative low strength of composites, **careful occlusal assessment** is essential.

Key points

- The success of indirect restorations depends on patient, material and operator factors.
- The choice of material depends on specific clinical needs and patient preferences.
- Popular materials include cast metal alloys, titanium and resin-based composites.

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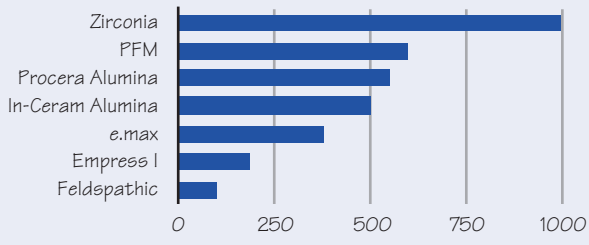
31 Ceramic materials

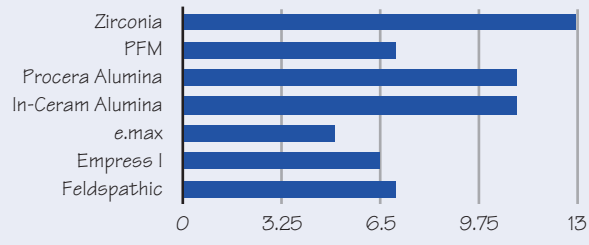
Ceramics

	Feldspathic (Silica-based ceramic)	PFM	Pressed ceramics (Silica-based ceramics)	Alumina-based ceramics	Zirconia-based ceramics
Uni- or bi-layered restorations	Uni or bi-layered	Bi-layered	Uni or bi-layered	Bi-layered	Bi-layered
Advantages	Life-like appearance, ideal for veneering metal or high strength ceramic substructures, smaller particle size reduces opposing tooth wear, amenable to hydrofluoric acid etching and silane for hermetic seal with tooth substrate	Long history of clinical success, forgiving clinical and laboratory procedures, non-adhesive cementation possible	Highly aesthetic, improved masking ability compared to feldspathic porcelain, pressable onto metal or high strength ceramic substructures, reduced plaque accumulation & opposing tooth wear, amenable to hydrofluoric acid etching and silane for hermetic seal with tooth substrate	High strength, controlled manufacturing process for fabricating substructures, good masking ability	Extremely high strength, indicated for a variety of single and multiple units, good masking ability, available in different colour ingots, reduced bacterial retention compared to titanium
Disadvantages	Weak, prone to fractures, unable to use non-adhesive or glass-ionomer cements, poor making of underlying tooth discoloration	Opposing tooth wear with older feldspathic formulations, veneering porcelain fracture, metal allergies, metal or opaquer shine through, greater plaque accumulation on metal lingual collars	Low strength, large connector dimensions for FPD	Unsuitable for posterior FPD, chipping of veneering porcelain	Chipping of veneering porcelain, inability to incorporate stress-relieving precision attachments, no long-term clinical data available for survival rates, high cost of CAD/CAM machines and fee/unit, reduced light transmission (48%) compared to alumina (72%)
Strengthening mechanism	None	Metal substructure has high strength for supporting porcelain	Leucite glass or lithium disilicate	Glass infiltration or densely sintered pure alumina (polycrystalline)	Infiltration and transformation toughening
Method of fabrication	Platinum foil, refractory die, CAD/CAM ingots	Lost wax for metal, Powder/liquid or pressed for veneering porcelain	Lost-wax, Powder/liquid or pressed for veneering porcelain, CAD/CAM ingots	CAD/CAM, and Powder/liquid or pressed for veneering porcelain	CAD/CAM, Powder/liquid or pressed for veneering porcelain
Clinical indications	Inlays, onlays veneers, porcelain jacket crowns (PJC)	Single and multiple anterior and posterior units	Inlays, onlays, veneers, all-ceramic anterior crowns, anterior bridges	Anterior and posterior single units, and anterior 3-unit FPD, implant abutments	Anterior and posterior single and multiple units, implant abutments
Recommended luting agent	Conventional resins	Zinc phosphate, polycarboxylate, glass ionomer and resin cements	Conventional resins	Resin-modified glass-ionomer or adhesive resins	Resin-modified galss-ionomer or adhesive resins
Proprietary products	Numerous	Numerous	Empress I®, e.max®, Cerinate®, Fortress(™)	In-Ceram® Alumina, Procera® Alumina	In-Ceram® Zirconia, Procera® Zirconia, Lava® Zirconia, Cercon®, e.max® ZirCAD, Vita® YZ Cubes, DC Zirkon®, Everest(™)
Longevity	Brittle, location in mouth and type of restoration determines durability	Excellent, > 95% over 10 years, > 70% for 15 years, and > 50% for 30 years	> 90% over 10 years for anterior units, less for posterior units and FPD	Anterior single units > 95% over 10 years	Good short & medium term performance, long-term clinical data unavailable

Comparison of mean flexural strength (MPa)



Comparison of mean hardness (GPa)



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Ceramics are a significant class of **indirect restorative materials** that are revolutionising contemporary dentistry. The main reason is their **lifelike appearance** compared to metal-ceramic or all metal restorations.

Overview

Ceramics are **inherently brittle materials** and susceptible to **fracture**. Microscopic imperfections within the material are termed **Griffith flaws**, which grow into **cracks**, and if unimpeded, lead to **catastrophic fracture** of the ceramic. The cracks are propagated by the hostile oral environment: **dynamic (occlusal forces)** and **humid (stress corrosion)**. Furthermore, **static fatigue** is **time-dependent**, which eventually results in breakage. Many strengthening mechanisms are used for halting fracture propagation including **reinforcement** and **infiltration** with glasses as well as **phase transformation toughening**. Preventing fractures also depends on the **clinical scenario**, **method of fabrication** of the restoration, and the **manufacturing technique and strengthening** process of a specific ceramic.

For the reasons cited above, in order for ceramics to survive in the oral cavity, they must be **supported**, either by the **natural tooth substrate** or an **artificial substructure**. Two types of ceramic restorations are possible: first, a **uni-layer restoration** that is entirely composed of ceramic and gains support from the underlying tooth substrate, and second, a **bi-layer restoration** with a substructure to support the veneering porcelain. The **substructure** can be of either **metal**, or a **dense high strength ceramic**.

Classification

Many **classifications** have been proposed to categorise ceramics depending on **material composition** (type of matrix and filler), **aesthetics properties** (translucency), **strengthening process**, **method of fabrication** (manual or milling), and **manufacturing process** (powder/liquid or ingots), etc. The simplest classification of ceramics is based on the material from which they are made, i.e. **silica**, **alumina** or **zirconia**.

Silica

Silica-based ceramics have a **high glass content**, making them **highly aesthetic**. These dental ceramics have **excellent optical properties** due to the addition of filler particles for enhancing opalescence and fluorescence, and shades to mimic the colour of natural enamel and dentine. However, their drawback is **lack of strength**, and they are therefore often used for **veneering stronger substructures**. Examples include **aluminosilicate glass**, e.g. **feldspathic**, **synthetic porcelain**, and **leucite reinforced**. Silica-based ceramics can be strengthened by the **addition of filler particles** to the glass base, e.g. **lithium disilicate**, and are termed **glass ceramics**. They are used for fabricating all-ceramic restorations, either as the **entire restoration form** (**uni-layered**), or acting as **substructures** for subsequent veneering (or layering) with weaker feldspathic porcelain (**bi-layered**).

Metal-ceramic

Porcelain fused to metal (PFM) restorations have a metal substructure to support a weaker silica-based veneering porcelain. These restorations have **50 years history of clinical success**, and show versatility in the type of restoration that can be fabricated including single and multiple units on both natural teeth and implant abutments. In addition, they have established clinical and laboratory protocols, with **survival rates** greater than **95% over a 10-year period**. They are often used as a benchmark for assessing newer types of all-ceramic restorations. The major **disadvantage of PFM** restorations is poor aesthetics, particularly greying at the **cervical margins** due to visibility of the metal substructure or 'shine' through thin periodontal biotypes.

Alumina

Alumina-based ceramics have a **lower** or **no glass content** but **higher strength** than silica-based ceramics, and are available as two varieties. The **lower glass content** is a 3-D **interpenetrating phase** whereby molten glass (alumina, magnesium or zirconia) is infiltrated into the matrix, e.g. In-Ceram® Alumina and In-Ceram Spinell®. The second type of alumina has **no glass**, and is a highly packed **polycrystalline** structure, e.g. Procera® Alumina. Due to the **hardness** and poorer aesthetics of alumina, uni-layered restorations are impossible. The alumina substructure is usually veneered with silica ceramics to create **bi-layered restorations** with improved **aesthetics** and **reduced opposing tooth wear**.

Zirconia

Zirconia-based ceramics may eventually become a **universal all-ceramic** material. Technological advances are rapidly developing zirconia into a ubiquitous ceramic for use in single and multiple units in both anterior and posterior regions of the mouth. The **high strength** of zirconia allows fabrication of FPDs with connectors that have similar dimensions to metal substructures. Zirconia is available in **three phases**, depending on the amount of fillers, e.g. calcia, magnesia, yttria and ceria. The **cubic version** is fully stable at room temperature, while the **tetragonal phase** is partially stable. The latter phase changes to the **monoclinic phase** under stress and impedes crack formation. An infiltrated variety is also available, similar to the In-Ceram® Alumina, called In-Ceram® Zirconia. Zirconia restorations are exclusively fabricated using **CAD/CAM** technology either in its **chalky** or **fully sintered** states for **bi-layered** prostheses.

CAD/CAM blocks (ingots)

Most ceramics and composite resins are available as blocks (**ingots**) for numerous CAD/CAM milling machines. The advantage of ingots is that they are **manufactured in a controlled and repeatable process** compared to manual powder/liquid build-up or the **pressed processes**. The stringent industrial process confers **superior mechanical and physical properties**, with ingots **devoid of the porosity** that is prevalent in manual build-ups, layering or pressed ceramics. For example, a feldspathic ceramic block (ingot) has a flexural strength of 130 MPa, twice that of conventional layered feldspathic porcelains.

Key points

- Dental ceramics create lifelike restorations, but have a propensity to fracture.
- Ceramics can be classified as silica, alumina and zirconia.
- CAD/CAM technology is likely to revolutionise fabrication of indirect restorations.

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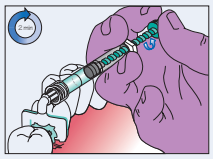
32 Micro-invasive and minimally invasive techniques

Caries infiltration concept

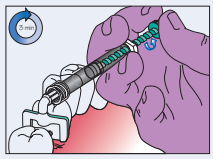
Bitewing

Bitewing radiograph showing early, interproximal, non-cavitated carious lesions



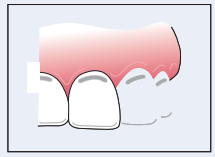
HCl

10% HCl for etching surface enamel



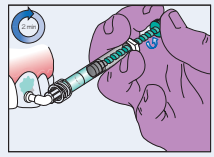
Infiltrate

Application of resin infiltrate to seal enamel porosities



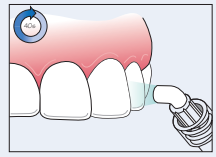
White spot

White spot lesion after removal of orthodontic brackets



HCl

10% HCl for etching surface enamel



Postoperative

Application of resin infiltrate for immediate improvement of aesthetics

Microabrasion

Preoperative

Isolation

Postoperative

Comparison of techniques

Technique	Constituents	Mechanism	Indications
Caries infiltration concept	10% HCl, ethanol and resin infiltrate	Chemical	Early, non-cavitated interproximal or facial carious lesions
Microabrasion	Various concentrations of HCl and abrasives	Chemo-mechanical	Superficial enamel staining, e.g. dental fluorosis
Air abrasion	Aluminium oxide, silica or bicarbonate soda particles	Mechanical	Cleansing fissures, removing early surface carious lesions, class VI carious and erosive cavities, removing small old composite restorations, removing superficial enamel stains, prophylaxis, and roughening composite cores before luting definitive indirect restorations
Carisolv	Gel combined with hand and rotary instruments	Chemo-mechanical	Caries excavation, especially in deciduous teeth
Lasers	Various types	Photo-mechanical	Caries excavation, especially in deciduous teeth
Oscillating tips	Fine grit diamond tips	Mechanical	Shaping cavities following caries or defective restoration removal

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This first section on tooth preparation discusses **micro-invasive and minimally invasive** techniques. These treatment modalities are minimally invasive, atraumatic, avoiding more traditional and invasive rotary techniques for tooth preparation.

Micro-invasive techniques

Caries describes the **process** and **lesion** of dental decay. Caries is an **infectious disease**, and the protagonist bacteria is *Streptococcus mutans*, which attacks dental hard tissues. The **driving force** of caries is not the bacteria per se, but the **biofilm** that contains the bacteria and carbohydrates. If the biofilm is removed or disturbed, caries can be **reversed** or **arrested by remineralisation** with calcium and fluoride ions present in saliva.

The earliest carious lesion is termed a **'white spot'** that can be **active** or **inactive**. Micro-invasive techniques such as the **caries infiltration concept** (Icon, DMG, Germany) aim to arrest early caries before cavitation occurs. This is probably the least invasive method of tooth preparation, involving etching with hydrochloric acid (HCl) and applying an **infiltrate** (low-viscosity resin) that penetrates and seals the lesion by **capillary action**. This treatment is indicated for early **interproximal** lesions, and is also effective for immediate **improvement of aesthetics** after removal of fixed orthodontic brackets.

Microabrasion

Microabrasion is recommended for removing unaesthetic staining that is limited to the superficial layer of enamel due to **fluorosis**, **prosthodontic demineralisation**, **localised hypoplasia** or other idiopathic brown/white enamel **dysmineralisation**.

Enamel fluorosis, especially of the maxillary anterior teeth, is due to excessive intake of fluoride (**greater than 1 ppm**) during the second and third years of life. The **source of fluoride** is from foodstuffs such as milk, salt, vitamins, infant preprepared food, and the indigenous water supply or dental preventive measures such as toothpaste and rinses. Although fluoride is an **anti-caries** measure, excess amounts prevents maturation of the enamel, increasing its porosity and presenting as **white**, **yellow or brown striations and staining**.

The **microabrasion** process involves simultaneous **acidic erosion** and **mechanical abrasion**. The technique uses a slurry of **HCl**, usually mixed with **pumice** or other abrasive, that is applied to the surface enamel either with a hand applicator, or using rubber cups in a slow dental handpiece. A **6% HCl** concentration reveals a **micromorphological** appearance that is similar to intact, untreated enamel without an etch pattern, and is less erosive than 37% phosphoric acid, confirming that this type of minimally invasive treatment **does not damage the structure of enamel prisms**. Also, fluorosed teeth are **hypermineralised**, with a higher concentration of fluoride in the outer **200 µm layer of enamel** that is more resistant to acid etching.

The technique involves isolating the teeth beforehand with conventional or light-cured **rubber dam** to prevent ulceration of the soft tissues. The slurry is applied and repeated until the stains are removed and an acceptable tooth colour is achieved. This is followed by application of **topical sodium fluoride** to encourage remineralisation of the enamel. A possible explanation for the **improvement in tooth colour** after microabrasion is that the acid penetration into enamel may **remove the retained amelogenin proteins** that are attributed to the lesion of enamel fluorosis. Furthermore, the polished tooth surface results in enhanced **specular reflection** that camouflages underlying enamel imperfections.

The **drawback** of microabrasion is the risk of **caustic burns** to the gingiva, and rubber dam is therefore mandatory. If the slurry is incessantly applied and the dentine exposed, **hypersensitivity** is possible. However, microabrasion should be considered the first line of treatment for removing intrinsic enamel stains before more aggressive restorative options are considered.

In **severe fluorosis**, a variation of the macroabrasion technique is to use fine **diamond burrs** (60 µm grit) for initial removal of intense fluorotic stains and to adjust the macromorphology. The enamel surface is then **polished** with aluminium oxide discs and silicone tips before continuing with the HCl slurry. In addition, office or home **bleaching** is prescribed to lighten the teeth. This combination of chemical and mechanical abrasion is often referred to as the **chemo-mechanical** approach.

Other methods

Other methods of minimally invasive tooth preparation include **air abrasion**, which is a mechanical method for roughening the tooth substrate to increase mechanical retention for resin-based fillings. Particles of silica, **aluminium oxide (50 µm)** or bicarbonate of soda are jetted onto the tooth from a dental handpiece using compressed air. The procedure is painless, rarely requiring anaesthesia. A wide range of clinical applications are possible, ranging from cleansing fissures, to removing small old composite restorations. Necessary **precautions** include wearing protective glasses, isolation of the affected teeth with rubber dam to prevent inhalation, and avoiding contact with intact resin-based or glass ionomer fillings.

Treatment of small cavitated carious lesions, especially in deciduous teeth, or cleansing fissures of organic debris before sealing, can also be achieved with other minimally invasive protocols. **Carisolv®** is a chemo-mechanical technique using a gel to dissolve denatured collagen in cavitated carious lesions, followed by hand and rotary instrumentation for debridement of the cavity. **Lasers**, e.g YAG:Er CTL-1601 are also employed for painless carious excavation. Finally, **oscillating diamond tips**, which are less invasive than burs, are useful for shaping cavities following caries removal.

Key points

- Micro-invasive and minimally invasive tooth preparation techniques are aimed at preserving as much natural tooth as possible.
- The caries infiltration concept is the least invasive method for treating early carious 'white spot' lesions.
- Microabrasion is atraumatic and highly effective for restoring aesthetics due to superficial enamel staining.
- Other minimally invasive preparation techniques include air abrasion, Carisolv®, lasers and oscillating diamond tips.

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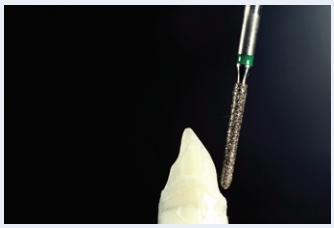
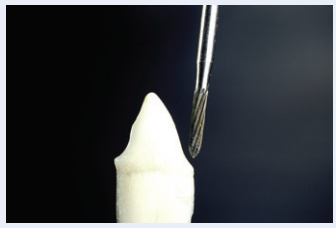
33 General guidelines for rotary tooth preparation

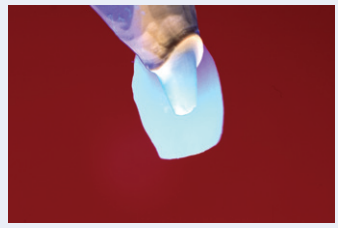
Dental burs



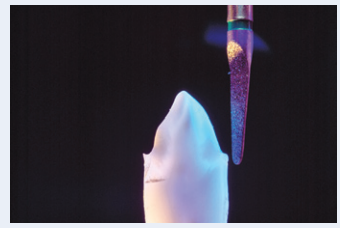
Initial bur - 125 µm



Final bur - 12 fluted TC



Sinuous preparation



EVA bur to remove unsupported enamel margins

Soft tissue integrity

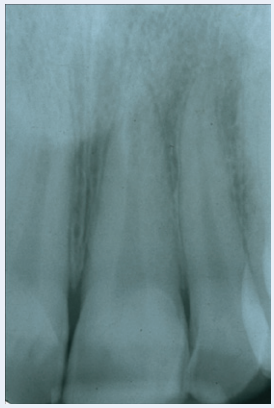
Flat plastic and Zekrya retractor

Zekrya retractor

Gingival retraction cord to protect gingiva

Gingival retraction cord

Hard tissue integrity



Pulp chamber size

Copious irrigation

Intermittent preparation

Immediate dentine sealing

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Conventional **tooth preparation** involves using **rotary instruments** in preparing teeth to receive either direct or indirect restorations, and is currently the most widely used method worldwide. Tooth preparation is potentially destructive to both the hard and soft tissues, and should be carried out **efficaciously**, **expediently** and with extreme **care** to avoid inadvertent or **iatrogenic trauma**. The guidelines presented below are applicable to all types of tooth preparation using **rotary instruments**.

Instrumentation

Rotary instruments refer to burs that prepare a tooth by either **grinding** or **cutting**. A **dental bur** has a **stainless steel shank** with blades of various geometries and shapes. Alternatively, the bur shank can be **coated with diamond grits** or **tipped with tungsten carbide (TC)** blades or flutes, for cutting or polishing, respectively. The most popular variety are diamond burs, which are classified according to their **shape**, **size** and the **diamond grit particle size** that varies from **10 µm** to over **200 µm**. The bur shank fits either a **friction grip (FG)** turbine handpiece, or a latch-type attachment of a micro-motor **contra-angle (CA)** handpiece. The specifications of handpieces vary according to the manufacturer, but are broadly divided into **turbines** rotating at speeds above **300,000 rotations per minute**, while the slower **micro-motors** speeds vary from **1,000 to 40,000 rotations per minute**, depending on **torque** and **gear reduction/increasing ratios**.

Soft tissue integrity

The **soft tissues** of the oral mucosa, tongue and lips should be sufficiently **retracted** to allow a clear field of view and to prevent lacerations by the rotary instruments. The circumferential friable **gingival margin** requires special attention, to minimise not only transient but also long-term effects of trauma. The **initial trauma** is bleeding, which hinders clinical procedures such as margin visualisation, impressions and cementing procedures, while **long-term** effects includes persistent **gingival inflammation**, **periodontal pockets** or unwanted **gingival recession**, compromising 'pink aesthetics' in the anterior regions of the mouth. **Gingival recession** is highly likely with **pronounced scalloped gingival** contours and/or **thin biotypes**. **Protection** of the gingiva is by transient retraction using hand instruments such as small **flat plastics**, **Zekrya** gingival retractor, and **retraction cords**. All these methods provide protection against inadvertent violation of the **biologic width**, and for promoting a **haemorrhage-free** protocol.

Hard tissue integrity

Besides soft tissue protection, it is also essential to protect the **dental hard tissues**: enamel, dentine and the alveolar housing of teeth, to avoid morbidity or mortality. The long-term eventualities are **endodontic complications**, **bone resorption** and **periodontal pockets**. Various studies have endeavoured to evaluate the number of teeth undergoing pulpal pathosis following tooth preparations. The number of teeth **losing vitality** following full coverage crowns has varied from as little as **2% to over 13%** over a 10-year period. Therefore, any tooth scheduled for full coverage crowns should have a preoperative endodontic assessment including history of previous symptoms, clinical and radiographic examination, and vitality tests.

The two factors for maintaining **hard tissue integrity** of teeth are **cutting efficiency (CE)** and **temperature elevation**. Cutting efficiency is defined as the most expedient method for tooth preparation. The critical threshold for CE of **diamond grit size** is **150 µm**. A larger diamond grit size does not increases CE, but leads to **microscopic cracks** in the enamel and dentine, which weakens the remaining tooth substrate. In addition, the **roughened surface** created with coarser burs leads to a greater surface roughness (**Ra**), which **complicates** laboratory procedures such as **waxing and casting**, and introduces **porosity** in the **luting agent** at the cementation stage. Furthermore, the coarser grit generates heat precariously close to the **pulpal necrosis** temperature of **41.5°C**. Hence, it is prudent to choose burs with a grit size of <150 µm and **progressively reduce the grit size** as the preparation approaches dentine, to prevent overheating and to create a smoother surface finish.

Other factors to consider during tooth preparation are:

- **Size of pulp chamber**, which should be assessed radiographically and the amount of tooth reduction carried out precisely with **silicone indices**. In **young teeth**, the pulp is larger than in **older teeth** because the pulp chamber in the latter is reduced due to deposition of **secondary dentine** in response to carious, restorative, occlusal and extra-oral traumas;
- **Preservation of natural tooth substrate** is essential to ensure **tooth rigidity** and **insulation** from temperature fluctuations, and to prevent **impregnation of the dentine tubules** with oral pathogens;
- **Non-vital teeth** are **structurally compromised** with **reduced proprioceptive response**, predisposing them to **fracture**. Care is therefore necessary to design extracoronal restorations that enhance the fracture resistance of the remaining tooth. Teeth with **intraradicular support** are prone to coronal microleakage that may compromise the root filling as well as the final restoration;
- **Cooling** with copious irrigation at water temperatures below 32°C mitigates the frictional heat generated during preparation;
- **Pressure** applied during tooth preparation should be **minimal** and **intermittent** to reduce temperature elevation, and allow heat dissipation. Excess pressure is often necessary if **burs are damaged**, **degraded or clogged with debris**. Ideally, burs should be discarded after a single tooth preparation, or cleaned in an ultrasonic bath before sterilisation. Furthermore, the trauma to the dental pulp is cumulative. Heavily or repeatedly restored teeth are especially vulnerable to additional trauma of tooth preparation, which may result in pulpal necrosis;
- **Time** taken to prepare a tooth should be an absolute minimum. Relentless and protracted preparation is unproductive, often resulting in endodontic complications;
- **Immediate dentine sealing** of prepared teeth with a **dentine bonding agent (DBA)** removes the smear layer, **seals patent dentine tubules**, **halts bacterial ingress**, **reduces postoperative sensitivity** and results in **superior bonding** of the definitive restoration when using a resin-based cement.

Key points

- The use of rotary instruments or burs is the most popular method for preparing teeth for direct and indirect restorations.
- Tooth preparation is potentially destructive and caution is necessary to maintain both soft and hard tissue integrity.

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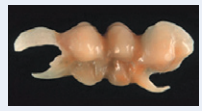
34 Preparation for resin-bonded fixed partial dentures

Anterior (facial view)

Anterior (incisal)

Cantilever RBFPD


Posterior RBFPD

D-shaped retainer

C-shaped retainer

Anterior metal RBFPDs are useful as temporary measures awaiting a more permanent solution. The metal wing retainers can cause greying, especially with thin incisors.

Posterior RBFPDs have a metal wraparound retainer on the lingual or palatal surfaces. The retainer can be C- or D- shaped, extending onto the occlusal surface

Anterior — METAL — Posterior

RBFPD

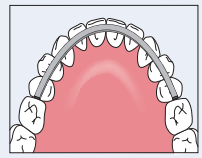
Anterior — FRC — Posterior

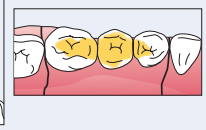
Anterior (framework)

Anterior (try-in)

Cantilever FRC

Intracoronal FRC


Extracoronal FRC


Cantilever FRC

FRC FPDs are reinforced with fibres instead of metal, and are more aesthetic, especially for the anterior regions of the mouth

FRC can either be intracoronal ('inlay' retained), or full coverage (extracoronally retained). For posterior teeth, the pontic sites can be further strengthened by incorporating multidirectional fibres, or rods

Advantages and disadvantages of RBFPD

Advantages	Disadvantages
Minimal tooth preparation	Survival rate of 5 years
Excellent short-term prostheses for young patients, and while awaiting healing of bone and soft tissue grafts and implants, splint mobile teeth	Debonding likely, especially with parafunctional habits
Choice of metal, composite and ceramic frameworks	Short-span bridges, limited to 2 or 3 units
Economical compared to conventional FPD or implants	Exacting adhesive protocol for cementation

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Resin-bonded fixed partial dentures (RBFPDs) were introduced by **Rochette** in 1973 for splinting periodontally compromised mandibular anterior teeth. The indirect prosthesis is made of **perforated cast metal retainers** or **wings**, with or without pontics, which are cemented to the lingual or palatal surfaces of abutment teeth with a resin-based luting agent. RBFPDs are **minimally invasive**, requiring less tooth preparation compared to conventional FPD. They are usually indicated for short spans of two or three units. Longer spans are possible if the occlusion is satisfactory without bruxist activity. However, increasing the number of abutments causes interabutment stresses leading to a greater chance of **debonding**. RBFPDs are indicated for anterior and posterior regions of the mouth, with the following uses:

- As **minimally invasive fixed prostheses** for unrestored, intact adjacent teeth, teeth in younger patients with large dental pulp chambers, or following acute trauma resulting in avulsion of a tooth;
- As **temporary** or **stopgap prostheses** to allow integration of hard and soft tissue augmentation, while awaiting implant placement or during the osseointegration phase of implant therapy;
- A **short-span FPD** as an alternative to conventional FPD or implant-supported prostheses;
- For **splinting** mobile, periodontally compromised teeth.

Several **configurations of RBFPD** are described. These include retentive wings either side of the pontic, or a **cantilever design**, using only one abutment tooth for the retainer, with a suspended pontic. For the latter, the pontic on the opposite side of the retainer can be supported by an **intracoronal rest seat** for correct location and stability. RBFPDs have approximately **90% survival rate over a 5-year period**, with greater success reported in the maxilla than the mandible.

Rochette and Maryland appliances

Both the **Rochette** and **Maryland** FPD are fabricated from cast metals and their fitting surfaces etched in the dental laboratory. The difference between the two is the design of the metal retainers: the **Rochette retainers are perforated** to increase mechanical retention, while **Maryland retainers** are **non-perforated**. If a pontic is incorporated, its metal substructure can be veneered with a resin-composite or porcelain. The **drawbacks** of metal retainers are the metal shine-through or greying of thin abutment teeth, debonding and overcontoured retainers.

Fibre-reinforced composite

To improve aesthetics, gain additional retention and reduce opposing tooth wear, cast metal retainers can be substituted with a reinforced resin composite. **Fibre-reinforced composite (FRC)** FPDs are composed of two types of composite:

- **Substructure** – either pre-impregnated fibres in a resin matrix or non-impregnated polyethylene fibres;
- **Superstructure** – a hybrid or micro-filled veneering composite bonded to the substructure composite with heat and light polymerisation. To prevent delamination and create high bond strengths, it is essential to **maintain an oxygen inhibition layer** between composite increments, or to condition the substructure composite with a **silane coupling agent**.

FRC FPDs can either be **full coverage (extracoronal)** or **partial coverage (intracoronal)** 'inlay' retained, depending on the restorative status of the adjacent abutment teeth.

The **framework design of FRC** depends on whether full or partial coverage is planned. Nevertheless, the framework should offer sufficient rigidity to support the veneering composite and resist occlusal forces, which is achieved by incorporating multidirectional fibres, adequate bulk of fibres, and including bars at pontic sites.

Tooth preparation

The tooth preparation for an RBFPD depends on the existing restorations in the abutment teeth. **Heavily restored teeth** with extensive amalgams or composite filling require **full coverage** type of preparations, while for smaller class I, II and III restorations an **intracoronal** approach is appropriate. In addition, **retentive features**, preferably confined within the enamel, such as proximal/occlusal grooves and lingual steps are beneficial and avoid over-contoured prostheses and sufficient occlusal clearance. For **intact**, **virgin teeth**, no preparation is usually necessary, except creation of guiding planes, occlusal stops and finish lines for path of insertion and location, respectively.

Prosthesis design

Metal substructures or **frameworks** can be fabricated from both **noble and base cast metals**, such as nickel chrome alloy. The framework is designed for **maximum extension onto the lingual/palatal surfaces** to increase the surface area for bonding, without compromising aesthetic, occlusion or periodontal health. For molar abutments, the framework is wraparound to maximise retention and resistance form, and can be either **C-shaped**, confined to the lingual surface, or **D-shaped**, extending onto the occlusal aspect. In addition, the **retainer thickness should be >0.8 mm** for sufficient strength. Other options include fabricating a high-strength **CAD/CAM ceramic framework**, with pressed or layering veneering porcelain for the pontic.

Cementation

Luting an RBFPD involves using an **adhesive bonding technique**, which is operator-sensitive and influences the longevity of the prosthesis. A **conventional** or **adhesive resin-based luting agent** is recommended. The **intaglio surface** of the retainers is pre-treated with **air abrasion**, **electrolytic etching** or **silanation**. The **fitting surface** of the abutment tooth can also be air-abraded and/or etched with 37% phosphoric acid to enhance bonding. Since dentine is rarely exposed, the bond to enamel is more predictable, assuming proper isolation to prevent contamination by saliva and blood.

Key points

- Resin-bonded fixed partial dentures are minimally invasive, indirect prostheses.
- They are indicated for a variety of clinical applications, and have a survival rate of approximately 90% over 5 years.
- The framework can either be cast metal or fibre-reinforced composite that is veneered with either resin-based composite or porcelain.
- An adhesive technique is necessary for luting RBFPDs using resin-based cements.

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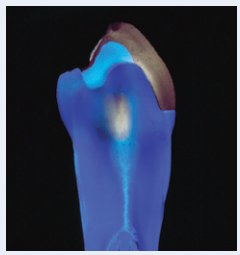
35 Preparation for inlays and onlays

Cavity configurations

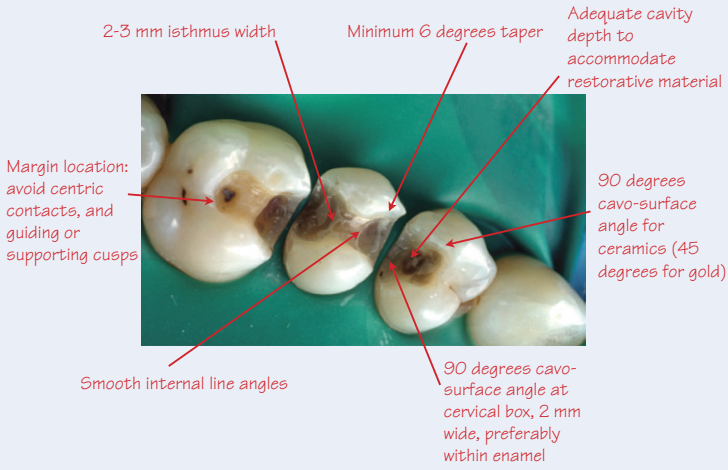


Inlay | Onlay | Inlay+onlay | Veneer+onlay (Veneerlay)

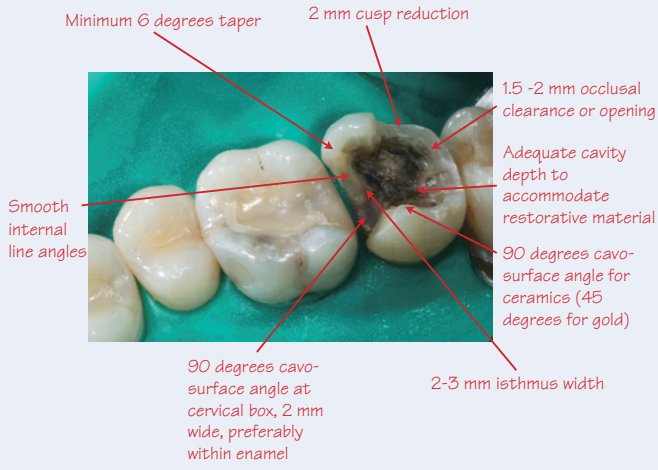
Compressive strength of enamel and dentine according to the type of restoration

Intact tooth > Inlay > Onlay

Inlay preparation



Onlay preparation



Inlay preparation

Guidelines for inlay preparation include taper, cavity depth, isthmus width, internal and external line angles, and occlusal and cervical margin location

Onlay preparation

Guidelines for onlay preparation incorporating cusp(s) include sufficient cusp reduction (minimum 2 mm) and occlusal clearance (minimum 1.5 mm)

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Conventional teaching stipulates that tooth preparation be **material-orientated**, i.e. **geometric**, to accommodate the properties of the restorative material. Conversely, contemporary techniques dispel this destructive overpreparation in favour of **disease- or defect-orientated preparations**. Modern restorative materials are capable of restoring teeth that have smaller or minimally invasive preparations, and therefore allow a larger amount of natural dental tissues to be retained.

Indirect inlays and onlays are indicated for **extensive cavities** in **premolars** and **molars**, due to rampant caries, or to replace defective existing restorations. An inlay or onlay preparation **conserves more of the natural tooth**, removing less tooth substance (**6–27%**) compared to a **full-coverage crown** (**68–76%**).

Definitions

An **inlay** is an **indirect intracoronal restoration** that does not support or replace cusps of a tooth. Furthermore, all occlusal contacts in centric, protrusive and lateral excursions are guided by cusps of the natural tooth.

An **onlay** is an indirect restoration that incorporates, supports and replaces one or more tooth cusps. The functional occlusion is supported by the restorative material that covers the involved cusps. An onlay can incorporate an inlay preparation or be restricted to the occlusal surface to replace an eroded occlusal table, or to raise the occlusal vertical dimension (OVD).

Various cavity configurations of onlays and veneers are possible; for example, a **veneerlay** restoration that combines an onlay and veneer preparation.

Guidelines for inlay preparation

The conventional guidelines for **inlay** preparations are:

- **Taper** – the occlusal and cervical boxes should have 6° tapers for adequate path of insertion/withdrawal;
- **Isthmus width** – 3 mm at the mesial and/or distal aspects;
- **Cavity depth** – 3 mm to accommodate an adequate bulk of restorative material (cast gold, composite or ceramic);
- **Internal line angles** – smooth, **devoid of undercuts**;
- **External line angles** – occlusal and cervical box finish lines should have a **90° cavo-surface angle for ceramics and composites**, and a **45° bevel for cast gold** to allow burnishing;
- **Occlusal margin location** – avoiding centric contacts, or guiding/supporting cusps;
- **Cervical margin location** – finish line within enamel, and if possible, coronal to the cement-enamel junction.

However, the ongoing improvement in material properties and refined clinical techniques afford greater latitude, allowing a more **defect- or disease-orientated preparation**. In the past it was essential to remove minor undercuts (either due to caries or existing amalgam fillings retained by undercuts) by removing enamel at the occlusal surfaces to expand the cavity. But now the **undercuts can be filled** with relative ease using dentine bonding agents (DBAs) and flowable composites. Alternately, **minor undercuts can be left in situ**, since modern impression materials are flexible enough to allow removal of the impression without distortion or tearing, and the undercut can be subsequently blocked out on the plaster cast in the dental laboratory.

Guidelines for onlay preparation

Tooth preparation for **onlays** follows similar guidelines for inlay preparation, but offers greater leeway. An **onlay preparation can incorporate an inlay preparation**, or **cover the entire occlusal table** without an inlay preparation. In the former situation, an inlay preparation is carried out, and if deemed necessary, **susceptible cusps are reduced by 2 mm** to accommodate the restorative material. The cavo-surface finish line is 90° for ceramics and bevelled 45° for cast gold. An onlay is prescribed because of severe coronal destruction and ensuing loss of tooth substrate resulting from tooth wear, decay or endodontic complications, and for restoring or raising the **OVD**. In these circumstances, the preparation is minimal, limited to **defining finish lines** with correct cavo-surface angles. Finally, a minimum of **1.5–2 mm occlusal clearance** or **opening** (if increasing the OVD) is necessary for the restorative material.

Recent research has verified that irrespective of the number of cusps (both functional and non-functional cusps) incorporated into an onlay preparation, the fracture resistance of the indirect restoration is unaffected, and can even restore the fracture strength to the equivalent of an unprepared, intact tooth. Furthermore, compared to inlays, onlays are more efficacious in protecting tooth structure because an onlay preparation design is more resistant to tooth fractures.

CAD/CAM inlays and onlays

The latest advances for fabricating indirect restorations in a few hours is by using **CAD/CAM technology**. The technique involves making an intra-oral **optical impression** of the preparation or extra-oral scanning of a plaster cast of the cavity. Using CAD/CAM computer software, a **virtual restoration** is designed, which is subsequently milled using **machinable ceramic ingots** (feldspathic, pressed leucite glass, lithium disilicate, alumina and zirconia). The milled restoration is polished, stained, glazed, etched and silanated, ready for adhesive luting.

The guidelines for tooth preparation for CAD/CAM restorations are identical to those for conventional fabrication methods. However, if an optical impression is utilised, **clearly delineated margins** and **sinuous line angles**, **devoid of undercut** are obligatory, with little room for error. In addition, the finish lines, when possible, should be located **supragingivally** to facilitate digital scanning of the preparation or a plaster cast of the preparation.

Key points

- Inlays and onlays are indirect restorations for large cavities in or on premolars and molars.
- Inlay and onlay preparations are more conservative than full coverage crowns, and the ensuing restoration can enhance fracture resistance of a tooth.
- CAD/CAM technology offers efficacious fabrication of various indirect restorations using a variety of ceramic and resin-based composite materials.

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36 Preparation for porcelain laminate veneers

INDICATIONS

Preoperative

Preparation

Cast

Postoperative

Preoperative

Wax-up

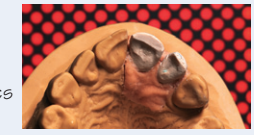
Postoperative

PREPARATION DESIGNS

0.4 mm cervical 1/3 and 0.7 mm incisal 2/3 preparation

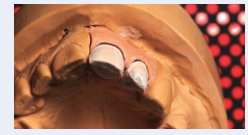
Buccal

Incisal wrap for superior aesthetics



Incisal edge

Ideally, supragingival margins



Cervical

Break contact points

Interproximal

PREPARATION GUIDELINES

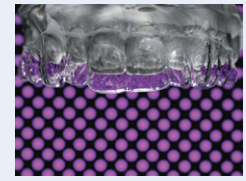
Incisal cut

Silicone index

Incisogingival cut for axial reduction guide

Silicone index

Clear stent for mock-up & temps



Stent

Protect soft tissues

Gingival protector

PLV PREPARATION FEATURES

 Prosthodontics at a Glance, First Edition. Irfan Ahmad. © 2012 Irfan Ahmad. Published 2012 by Blackwell Publishing Ltd.

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Porcelain laminate veneers (PLVs) have proved to be one of the most **successful and long-lasting** indirect **aesthetic restorations**. However, PLVs are also one of the most **clinically and technically challenging** restorations, and their success is attributed to careful and meticulous protocols. PLVs are the most frequently **used and abused** restorations in **cosmetic dentistry**, especially in the case of '**extreme make-overs**'. In addition, careful analysis of the patient's psyche is essential before embarking on irreversible **elective cosmetic procedures**, particularly if expectations are beyond clinical feasibility.

Rationale

The ethos of PLV is based on the principles of **preserving as much natural tooth substrate as possible**, especially enamel, and utilising this natural hard tissue **foundation to support thin veneers of porcelain**. Generally, **resin-bonded** PLVs require **¼ to ½ tooth reduction** compared to complete coverage crowns. In addition, PLVs conserve natural tooth structure, tooth vitality, rigidity and structural integrity, prevent postoperative sensitivity and therefore ensure longevity of both the tooth and veneering porcelain.

To prevent mutilation of tooth structure for spurious short-term aesthetic gains, it is worth remembering the following dictum before prescribing PLV:

> **The purpose of PLV is replacing lost enamel and dentine**
> ***not***
> **As a substitute for enamel and dentine**

Indications for porcelain laminate veneers

PLVs are primarily **aesthetic restorations** for improving tooth **colour**, **morphology** and **alignment**. They are usually placed on **buccal surfaces** of teeth in the **maxillary anterior sextant**, but are also indicated for:

- **Space management**, e.g. diastemata closure, or correcting imbrications;
- **Restitution of occlusal vertical dimension (OVD)** using the **Dahl concept**, following bite collapse due to tooth wear;
- **Combination restorations**, e.g. veneerlay (combination of a veneer and an inlay or onlay);
- **Palatal veneers** due to fracture, erosion or breakdown of defective restorations.

Preparation designs

Unlike crown preparations that have predefined geometric configurations to provide retention and resistance form, PLV **preparations** are **non-retentive** and entirely **dictated by a diagnostic wax-up**. Consequently, there is **no ideal preparation design**, and tooth reduction **(if necessary)** is **influenced by** aesthetics objectives, occlusal and functional needs, endodontic and periodontal considerations, amount of remaining tooth substrate, existing fillings, tooth morphology and alignment, choice of ceramic and the patient's wishes.

There are four **aspects** to consider for PLV preparations:

- **Buccal (facial)** – retain ⅔ to ¾ enamel for maintaining enamel rigidity, finish lines within enamel, cervical ⅓ reduction of 0.4 mm, and remaining ⅔ facial reduction of 0.7 mm;
- **Incisal edge**
  Window – conservative, poor aesthetics;
  Feather-edge – conservative, chipping at incisal edges, poor aesthetics;
  Incisal wrap (with palatal chamfer, bevel or butt joint) – invasive, superior aesthetics, requires 1 mm occlusal clearance, allows tooth lengthening (especially following tooth wear);
- **Cervical** – ideally margins within enamel, supragingival or subgingival to mask discolouration and conceal porcelain/tooth interface;
- **Interproximal** – retain or break contact points depending on clinical situation and treatment objectives.

The PLV preparation should feature **clearly defined finish lines**, **smooth surface roughness**, a **sinuous outline** devoid of undercuts, and **sufficient space** to accommodate adequate porcelain thickness for strength and to prevent an over-contoured restoration. If preparation is unnecessary, any **aprismatic enamel** should be roughened using **microabrasion** techniques to enhance bond strength before luting the veneers with dentine bonding agents (**DBAs**). **Pre-existing composite fillings** can reduce bond strength and may require replacement beforehand, or during the cementing process.

Preparation guidelines

A **diagnostic wax-up** is the starting point for PLV preparations. It allows **3-D visualisation** of the proposed outcome, and is preferred to 2-D image manipulation software simulations. Also, a diagnostic wax-up acts as a template for a **silicone index** (for guided tooth preparation), a **transparent vacuum-formed stent** or thermoplastic matrix (for intra-oral mock-ups and temporary coverage), and **a guide** for fabricating the definitive porcelain veneers.

Many **methods** have been proposed for tooth preparation including **freehand**, **silicone index guides** and cutting through **mock-up** simulations. The most precise method is using silicone indices, cut in several planes, to guide and minimise inadvertent tooth reduction. Tooth reduction is accomplished by placing **depth cuts** using **round diamond burs** of varying diameters. The depth cuts are joined for the **axial reduction** using straight-sided **135° chamfer burs** of decreasing particle size diamond grit, and smoothed with **tungsten carbide finishing burs**. The reduction should mimic the tooth curvature in all planes (mesiodistal, inciso-gingival) for ensuring an **even**, **predefined thickness of porcelain**. If required, **interproximal** contacts are broken with finely coated **diamond discs**. To **prevent laceration** of the gingival margins or interproximal papillae, the latter are protected by either **flat plastic instruments** or the **Zekrya gingival protector**. If dentine is exposed, **immediate dentine sealing (IDS)** using a DBA is advisable before impressions or fabricating provisional restorations.

Key points

- PLVs are highly aesthetic and predictable restorations, but require meticulous attention to detail for long-term success.
- There is no ideal tooth preparation (if required) for PLVs, which depends on the clinical scenario and treatment objectives, and is guided by a diagnostic wax-up.
- Preserving enamel is the key to success.

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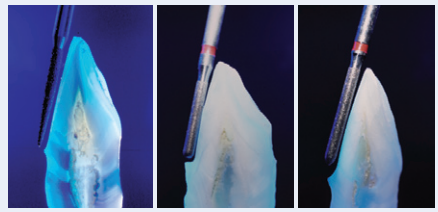
37 Preparation for full coverage crowns and fixed partial dentures

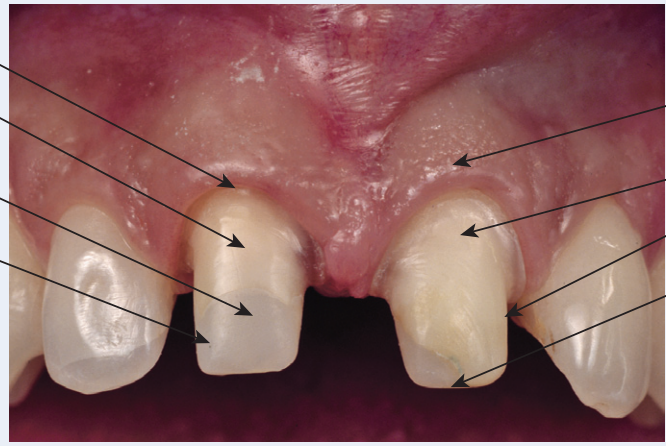
Margin location

Supragingival | Equigingival | Subgingival

Margin geometry

Knife-edge shoulder chamfer





IDEAL PREPARATION FEATURES

Preparation design

Remove unsupported enamel with reciprocating EVA diamond tip

Large connector dimensions for ceramics

FPDs

Small connector dimensions for metal

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Full coverage crowns or **abutments** for **fixed partial dentures (FPD)** on natural teeth are probably the penultimate indirect prostheses before considering extractions and implants. Furthermore, before embarking on these **highly destructive** preparations, alternative adhesive restorations such as onlays or **endo-crowns** should be considered. Full coverage crowns are also indicated for **implant-supported** single-unit crowns and FPDs, which minimises the number of implants required for oral rehabilitation.

Crown preparation is usually for **360° coverage**, but various **configurations are possible such as** ½, ¾, ⅞, etc., depending on the remaining tooth substrate. Essentially, **tooth preparation for crowns is material-oriented**, i.e. the tooth is prepared to accommodate the properties of specific restorative materials such as gold, resin-based composites or ceramics.

Margin location

The **preparation margins**, or **finish lines** can be placed in three locations:

- **Supragingival** – indicated for **low lip lines**, **posterior crowns**, **knife-edge finish lines** or **thin periodontal biotypes**. This is an ideal position since it allows both oral hygiene access, and clinical visibility for monitoring. Furthermore, gingival inflammation is minimal, and biologic width integrity is preserved;
- **Equigingival** – ideal when the underlying tooth colour is acceptable and an all-ceramic restoration is utilised;
- **Subgingival** – indicated for **high lip lines**, **profound tooth discolouration**, **masking or altering the unsightly tooth colour**, or for **all-ceramic crowns with a dense opaque core**, e.g. zirconia, to hide the crown/tooth transition. However, subgingival margins should only be considered for **thick periodontal biotypes**, which have less propensity for postoperative gingival recession, and located **within the gingival sulcus** to prevent violation of the biologic width. For **subgingival carious lesions**, **crown lengthening** or **orthodontic extrusion** may be necessary to locate the finish lines in a more favourable position.

Margin geometry

Margin geometry describes the shape of the tooth preparation finish lines. Three basic shapes are possible: **knife or feather-edge**, **shoulder** (or butt joint) and **chamfer**. The **knife-edge** is minimally invasive and conservative, advocated for **full metal** crowns, especially in the posterior regions of the mouth. Because the preparation is minimal, the margin must be located supragingivally. The **disadvantages** include indistinct finish lines and larger margin opening compared to a butt joint, bulbous crowns due to under-preparation, and is therefore contraindicated for all-ceramic crowns. The **shoulder** preparation (90° to 120°) is more aggressive than a knife-edge margin. It is suitable for **PFM** and **all-ceramic** units. However, the internal line angles should be rounded, devoid of undercut. The **chamfer** preparation has a generally accepted **geometry angle of 135°** that allows a gradual shade tooth/crown transition, aids scanning for CAD/CAM fabrication, and is ubiquitously recommended for most **all-ceramic** units and **electroformed** crowns. Furthermore, because the **smallest CAD/CAM millings tips are 1 mm**, they cannot reproduce preparation detail below this threshold.

Preparation design

A crown preparation requires **retention form** to prevent dislodgement and **resistance form** to resist occlusal and masticatory forces. As a general guide, full metal crowns require less tooth reduction compared to PFM or bi-layer all-ceramic units. A preparation design should incorporate the following features:

- **Occlusal/incisal reduction** – 1 mm to 1.5 mm in all excursions for clearance, and for enhanced fracture resistance of the restorative material;
- **Axial taper** – ideal **4° mesial and distal taper** (or **8° convergence angle**), acceptable range is 6–15°, i.e. translating to a mesial and distal interproximal reduction of 0.75–1.5 mm;
- **Facial and lingual reduction** – 1–1.5 mm depending on the margin geometry, and the facial-lingual thickness of the tooth;
- **Incisal-gingival height** – a minimum of 4 mm is desirable for adequate resistance form. It may be necessary to build up or fill in deficiencies with resin-modified glass ionomer or resin-based composites or to incorporate retention grooves for added retention;
- **Sinuous outline**, **devoid of undercuts** and **smooth surface**, is essential for impression making, cementing, and facilitating fabrication of the restoration in the dental laboratory. Furthermore, **sharp line angles** may initiate **fractures** at the fitting or **intaglio surface** of all-ceramic restorations.

Also, the tooth preparation should **follow the contours and anatomy of the natural tooth**, retaining as much enamel and dentine as possible. Finally, serrated, **unsupported enamel margins** following preparation should be trimmed with either hand chisels, or preferably with **reciprocating EVA diamond tip** for delineating a clearly visible finish line.

FPD considerations

Tooth preparation for fixed partial denture (FPD) abutments is identical to single units but with the following additional considerations:

- **Parallelism** – all abutment teeth should have the same path of insertion/withdrawal. Various methods are available for achieving parallelism, e.g. as intra-oral jigs;
- **Connector dimensions** – are the weakest link of FPD frameworks, and their dimensions depend on the type of restorative material. Cast metal or titanium frameworks require less surface area for connectors than ceramics, e.g. **12–20 mm^2 is necessary for glass ceramics**, **9–16 mm^2 for alumina** and **zirconia and 6.25 mm^2** for porcelain fused to metal;
- **Pontic design and size** – e.g. ridge-lap, ovate, or modified ovate pontics depending on morphology of the alveolar ridge(s);
- **Precision attachments** – are incorporated to relieve stress in long-span FPDs. Precision attachments require additional space at the occlusal and interproximal areas, and can only be used with cast metal frameworks.

Key points

- Full coverage tooth preparation is highly destructive and requires careful consideration.
- Crown preparation involves considering margin location, margin geometry and preparation designs.
- Additional features for FPD abutments include parallelism, space for connectors, pontic designs and incorporation of precision attachments.

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38 Provisionals

PROPERTIES OF MATERIALS FOR PROVISIONAL RESTORATIONS

	ADVANTAGES	DISADVANTAGES
Metal	Pre-formed morphology, no matrix required, can be relined with self-cured resins	Require extensive adjustment to obtain good marginal fit, contact points and occlusion, poor wear resistance, poor aesthetics
Polycarbonate	Pre-formed morphology, no matrix required, can be relined with self-cured resins, good wear resistance, good aesthetics	Require extensive adjustment to obtain good marginal fit, contact points and occlusion
PMMA	Resilient, good wear resistance and aesthetics, heat and pressure polymerisation improves physical and mechanical properties of material, easy intra-oral relining, repaired with flowable composites, suitable for long-term use and long–span multiple units, can be reinforced with metal copings for increased strength for lengthy use, especially for the healing phase of implant-supported prostheses	High exotherm, unsuitable for intra-oral fabrication, high shrinkage, unpleasant odour, free monomer causes gingival irritation, requires matrix, higher cost for laboratory-fabricated provisionals
PEMA	Less exotherm than PMMA but higher than bis-acryl, suitable for intra-oral fabrication, selection of shades and stains, easily relined, and repaired with flowable composites, suitable for medium-term use, ideal for relining metal, polycarbonate and PMMA shell crowns	Poorer wear resistance than PMMA, prone to staining, considerable shrinkage, allergies to residual uncreated monomer, unsuitable for long-span multiple units for lengthy period of use, unpleasant odour
Bis-acryl	Most popular of all materials for provisionals due to ease of use and delivery via syringe mix, low exotherm, no objectionable odour, minimal shrinkage, stronger than PEMA, ideal for single and short-span multiple units, and suitable for long-term use	High cost and waste, matrix required, brittle, difficult to reline, unsuitable for long-span multiple units
UDMA	Light-cured, good mechanical properties, large selection of shades, good aesthetics, easier relining than bis-acryl,	High cost and waste, matrix required, high exotherm due to light-curing polymerisation
Resin-based composite restoratives	Excellent aesthetics, ideal for temporary veneers, can be uses with or without matrix but temporary cement is not necessary, also possible to make laboratory provisional to compensate for polymerisation shrinkage for improved mechanical and optical properties	Expensive, time consuming, difficult to distinguish natural tooth substrate and filling material and may require time-consuming removal and/or damage to tooth preparation
Modified composites	Low viscosity, ideal for intracoronal provisionals for inlays, matrix and temporary cement not necessary	Weak, prone to wear, poor interproximal and occlusal contacts, discolouration with food dyes, difficult to remove if undercuts present

Intra-oral technique for fabricating provisional

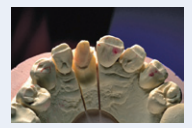
Impression or vacuum matrix

Tooth preparation

Dispense bis-acryl

Locate matrix

Preoperative



Preparation

Acrylic provisional

Fabricating an indirect vacuum matrix

Preoperative

Wax-up

Vacuum stent

Intra-oral vacuum stent

Provisional for inlays

Cavity preparation

Temporary inlay

Postoperative

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A provisional (or temporary restoration) is used as an interim before fitting the **indirect definitive** restoration or prosthesis. In essence, a provisional is disposable, but should remain for the intervening period while awaiting the permanent analogue.

Function of provisionals

Besides acting as a stopgap, provisionals have numerous useful functions for assuring the ultimate success of the permanent restoration, such as:

- **Health** – of **exposed dentine** and **pulp vitality**. In addition, **periodontal health** requires monitoring, especially if there is prevailing information due to previous **defective restorative margins**, **crown lengthening** or **implant and surgical augmentation**. Healing may be accompanied by gingival recession and may require **relocation of the preparation margins**, particularly for anterior restorations. In addition, a provisional is useful for **tissue sculpturing**, either at a pontic site or around implant abutments in order to achieve acceptable **'pink aesthetics'**;
- **Function** – for planned occlusal changes such as **anterior guidance**, **lateral excursions** and **vertical dimension** alterations. Also, the restorations should be **comfortable** and not an **impediment** to **phonetics** or **embouchure**;
- **Aesthetics** – when gross morphological changes are planned, e.g. restitution of **worn dentition** or for **elective cosmetic** procedures. Provisionals based on **diagnostic wax-ups** are minimally invasive, and are ideal for assessing aesthetics and function before carrying out irreversible tooth preparation;
- **Tooth preparation** – **sufficient tooth removal** in order to accommodate restorative materials using **intra-oral guides** for precise and calculated tooth reduction, e.g. for adhesively retained PLVs.

Choice of materials

The number of materials on the market for provisionals is both impressive and confusing, and the choice is dictated by the **intended use** and the **clinical scenario**. Materials for provisionals are broadly divided into metals and resins.

- **Metals** – **pre-formed** single crowns or short span FPDs without the need for a matrix, e.g. **stainless steel**, **aluminium**, **nickel and chromium**;
- **Resins** – **polycarbonate** (pre-formed single units), **PMMA** (polymethyl methacrylate), **PEMA** (polyethyl methacrylate), **bis-acryl**, **UDMA** (urethane dimethacrylate), **resin-based composite restoratives** (flowable and nonflowable) and **modified composites** (for inlays and onlays).

Techniques for fabrication

Nearly all provisionals require some type of **matrix** for fabrication. **Freehand** fabrication is possible but time-consuming, e.g. temporary composite veneers. The matrix can either be **pre-formed** or **custom-made**, which is the most popular method. There are two techniques for fabricating provisional: the **direct (intra-oral)** and **indirect (extra-oral)**. The **direct technique** involves using a matrix, for example:

- Based on **existing tooth morphology**, using a rigid and dimensionally stable impression material, e.g. polyvinylsiloxane putty, before tooth preparation;
- Based on **envisaged tooth morphology** from the diagnostic wax-up using a vacuum-formed thermoplastic matrix;
- **Pre-formed** metal or plastic shell crowns.

The **indirect technique (extra-oral)** involves using a dental laboratory or in-office casting of models. This technique is ideal for **long spans** that are intended for **lengthy periods of usage**, especially for **implant-supported prostheses** while awaiting osseointegration. Two methods are available:

- **Simulating tooth preparations** on a preoperative or diagnostic wax-up cast, and fabricating PMMA shells in the laboratory that are subsequently relined in the mouth using cold-cured resins after tooth preparation;
- Taking an **impression of the prepared abutments**, and then fabricating PMMA provisionals that are cemented with an appropriate temporary luting agent.

Provisionals for PLV present a challenge because little retention is offered from minimal tooth preparation. In these circumstances, if the preparation is within enamel and the contact points are retained, **no temporary restoration** is necessary. However, if dentine is exposed or contact points broken, the options are as follows:

- **Freehand composite build-up** with spot etching, without a bonding agent;
- **Composite**, **bis-acryl or PEMA**, either alone or in combination with a **vacuum-formed matrix** or **silicone impression matrix**, and then cemented with spot etching and a flowable composite. Also, **linking multiple provisional veneers** improves retention and prevents dislodgement.

Provisionals for intracoronal restorations such as **inlays** can be fabricated from a variety of resins, but the most popular materials are **light-cured modified composites** that are directly dispensed into the cavity preparation and set with a light-curing unit.

Temporary cements

A **temporary cement** should be strong enough to retain the provisional, yet weak enough for the practitioner to remove the restoration when necessary. Furthermore, it should be **palliating** to the hard and soft tissues, maintain **structural integrity** and **vitality** of the tooth, and promote **gingival health**. The most popular temporary cements are **zinc oxide/eugenol formulations**, available as non-eugenol and transparent varieties. Other cements include **zinc phosphate**, **polycarboxylate** and **flowable composites**.

To minimise the **marginal opening** between the provisional and tooth preparation margins, the provisional should not be overfilled; the temporary cement should be judiciously **applied to the cervical margins and axial walls**, but not to the occlusal intaglio surface.

Key points

- Provisionals are interim restorations used while awaiting the definitive restoration or prostheses.
- Properly constructed and accurately fitting provisionals are essential for the long-term success of the permanent restoration.
- A selection of materials is available for fabricating provisionals, using either direct or indirect techniques.

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39 Impression materials

CHOICE OF IMPRESSION MATERIALS

Preliminary impressions

Alginate, dental compound

Removable prosthodontics

Full dentures

ZnO/eugenol paste, light body PVS or polyether

Partial dentures

Monophase PVS or polyether

Fixed prosthodontics

Implants

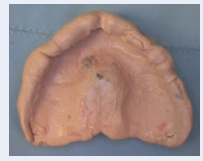
Monophase PVS or polyether, digital impression

Teeth

Dual-phase PVS or polyether, digital impression

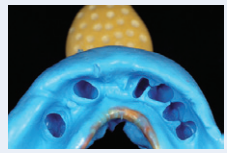
Edentulous

ZnO/eugenol

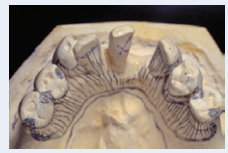


Wax addition

Partial edentulous ridge

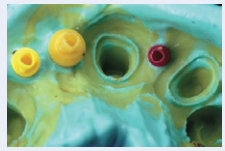


Mono PVS



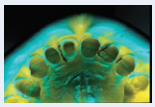
Plaster cast

Implants

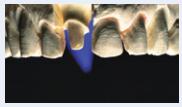


Impressions with impression copings

Implant abutments

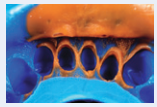


PVS (light+heavy)



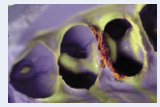
Plaster cast

Veneer prep

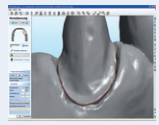


PVS (light+heavy)

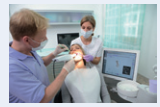
Inlay prep



PVS (light+heavy)



Crown prep



Digital

Veneer prep

Digital

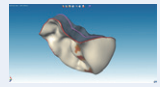
Inlay digital imp

Inlay CAD/ CAM design

Inlay CAD/ CAM design

Inlay articulation

Inlay fitting surface

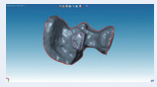


Inlay occlusal surface

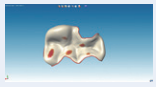
Onlay digital imp

Onlay CAD/ CAM design

Onlay articulation



Onlay fitting surface



Onlay occlusal surface

Tear resistance	Ability of a material to resist tearing in small cross sections, e.g. deep subgingival margins
Elastic recovery	The degree of recoil of a material without permanent elastic deformation, e.g. from tooth preparation undercuts
Dimensional stability	Ability to withstand stress without permanent deformation, e.g heavy body or putty formulations

Definitions

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Impressions are required for fabricating **indirect restorations** and **indirect prostheses**. The choice of impression material depends on the type of prosthesis. While some materials have multiple uses, predictable and precise impressions are achieved using specific materials for **removable** and **fixed prosthodontics**. Regrettably, substandard impressions are often accepted by clinicians in the expectation that the dental technician can **'fake and make'** missing or inadequate details of intra-oral anatomy. Precise and accurate impressions are **challenging** and require knowledge of:

- **Impression materials** (this chapter);
- **Impression techniques and armamentarium** (Chapter 40);
- **Soft tissue management** (Chapter 41).

Many impression materials used in dentistry since the 1950s are now archaic or redundant, including **plaster**, **polysulphides (rubber base)**, **reversible hydrocolloids** and **condensation silicones**. However, a minority of older-generation or esoteric clinicians still find use for these materials. The impression materials discussed below are the most popular in contemporary prosthodontics.

Dental compound

Dental compound is a **thermodynamic material** that softens with heat and sets to a rigid consistency in the oral cavity. Due to its thermodynamic behaviour, **additions or corrections** are relatively easy. However, its **low strength** and **brittleness** are drawbacks, often causing breakage, and uses include **customising stock trays**, **preliminary impressions** for full dentures, or supporting areas of **deep sulci** and **edentulous ridges**.

Zinc oxide eugenol paste

The use of **zinc oxide/eugenol paste** is exclusively for **tissue-supported** removable **full dentures** (RPD). The material's enduring property is that it does not **displace soft tissues of edentulous ridges**, **or buccal sulci**, thus avoiding **pressure spots** on fitting surfaces, and overextended buccal flanges, respectively. Furthermore, **voids** can readily be corrected by **adding wax** without repeating the impression. However, the material is unsuitable where there are profound **ridge undercuts**; it is also contraindicated in patients who **object to its pungent taste and odour** or who suffer from **eugenol allergy**.

Irreversible hydrocolloids

Alginates are irreversible hydrocolloids, frequently used for preliminary impressions for custom tray fabrication, opposing arch impressions, diagnostics (study models) making extra-oral provisional restorations, and for orthodontic cast records. Alginates are inexpensive and relatively technique-insensitive but dimensionally unstable, requiring almost immediate pouring.

Polyvinyl siloxane

Elastomers, e.g. **polyvinyl siloxanes** (PVS), and **polyethers**, are the most popular impression materials for **fixed prosthodontics**, including **implant-supported prostheses**. **PVS** materials, also known as addition silicones or vinyl polysiloxane (VPS), were introduced in the 1970s, as **addition reaction silicone elastomers**. Their popularity is attributed to **ease of use** (automix and cartridge delivery systems), **patient-friendliness** (odourless, insipid), **accuracy**, **dimensional stability**, **average tear resistance**, **good elastic recovery**, **long-term storage**, **multiple pouring**, immersible in **aqueous disinfectants**, and availability in a **range of viscosities and working/setting times** for innumerable impression procedures. In addition, PVS materials are suitable for **many impression techniques** including quadrant, full arch and one- and two-stage protocols using either **dual** or **monophase** consistencies.

Some disadvantages of PVS materials are that the setting reaction is retarded by **latex glove contamination**, which can be mitigated by using an automix machine or washing the tooth preparation with 3% hydrogen peroxide. Also, silicones are **hydrophobic (high contact angle)** and therefore impressions of subgingival crown margins may be problematic. However, as discussed in Chapter 41, efficient **soft tissue management** negates this unfavourable property.

Polyether

Polyethers are the second most popular impression materials for fixed prosthodontics. They offer excellent **accuracy**, **dimensional stability**, **superior tear resistance** and **elastic recovery**. Another benefit is their **hydrophilic (low contact angle)** property, facilitating impressions of deep intracrevicular restorative margins. Earlier polyethers had disadvantages of **high rigidity** and **pungent odour/taste**, but newer versions offer **lower viscosities** and are **tasteless**. A major drawback is that **multiple pours are not possible**, which are essential for modern laboratory fabrication procedures, especially when using CAD/CAM methods. Finally, due to their hydrophilicity, a **non-water-soluble disinfectant** is necessary.

Digital impressions

A **digital** or **virtual impression** uses a **scanner** to digitise the tooth preparation and sounding tissues, including the gingivae and adjacent and antagonist dentition. This can either be performed **intra-orally**, or from an **analogue impression** or **cast** of the tooth preparation. Software converts the digitised data into an image, which can be **manipulated**, **archived** and **disseminated** (e.g. to the dental laboratory) via the Internet. Using **CAD/CAM** software, the dental technician designs the restoration, and the resultant **computer file** is relayed to a milling machine where the restoration is fabricated.

The digital impression is an emerging technology, undergoing rapid changes, and has several advantages over analogue impressions, eliminating the following problems or dilemmas:

- **Material and tray selection**;
- **Material separation from tray**, distortion due to inadvertent handling or storage, and **damage** to, or **loss** of the **original impression** if a **replacement restoration** is necessary;
- **Expediency**.

Key points

- Impressions are necessary for indirectly fabricated prostheses.
- Choosing the correct impression material for a specific prosthesis is essential for success.
- Contemporary materials for analogue impressions yield reliable and predictable impressions.
- Digital impressions are the method of the future, but require further sophistication of existing equipment and software.

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40 Impression techniques and armamentarium

SINGLE-STAGE IMPRESSION TECHNIQUE

Measure arch width

Apply adhesive to plastic or...

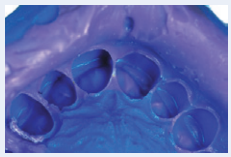
...metal tray

Air dry and wait 5 min

Load PVS heavy body in tray

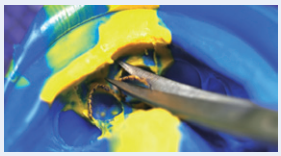
Tissue management

Light body onto abutments

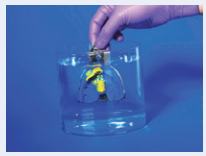


Impression

Trim excess material

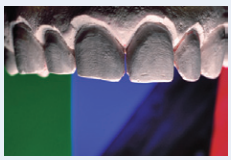


Trim loose cord

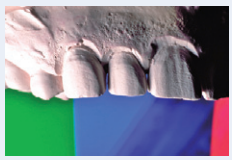


Disinfect with glutaraldehyde

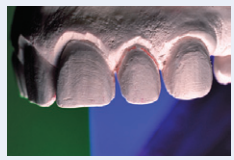
Plaster cast



Check for absence of voids and drags



Ensure finish line is clearly discernible

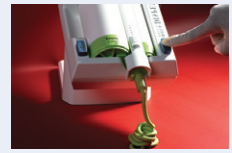


Ensure area apical to finish line is recorded

TWO-STAGE IMPRESSION TECHNIQUE

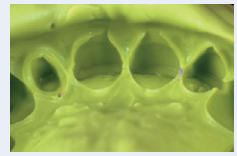
Apply adhesive

Load heavy body...

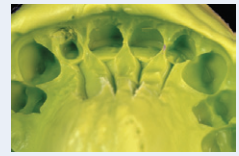


...and bleed material

Load PVS heavy body into tray



Take initial impression

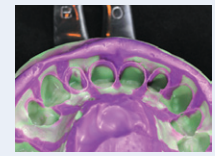


Trim channels...

... in entire tray

Tissue management

Light body on preparations and locate initial impression onto arch



Inspect impression

Untrimmed model

Trimmed model

Ensure finish line is clearly discernible

Ensure areas apical to finish line are recorded

Ensure areas apical to finish line are recorded

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Besides choosing the correct **impression material** for a specific restoration, the **technique** and **armamentarium** also influence the accuracy of an impression.

Tray selection

Rigid vs non-rigid: the rationale for using a **rigid** tray is to avoid distortion by controlling **dimensional stability** and minimising **polymerisation shrinkage**. Conversely, plastic or **non-rigid trays** cause distortion, even if using light-bodied materials. As a general rule, **plastic** trays are suitable **for single units**, but **metal** trays are preferable for **multiple units**.

Stock vs custom: **stock trays** offer convenience and disposability (plastic variety). Most **fixed prosthodontic** impressions are feasible on **metal stock trays** with modifications using dental compound material. However, well-adapted, **uniformly spaced (4 mm) custom trays** fabricated from **autopolymerising or light-cured resins** are an ideal choice for **removable prostheses**, **complex cases** involving a combination of teeth and implant-supported restorations, or if **voids and drags** are persistent in a stock tray impression. Also, care is necessary when using **rigid materials**, e.g. polyethers or putty-wash techniques, especially in the presence of **undercuts**, which may prevent removal of the custom tray after the material has set.

Perforated vs closed: the reasoning for using a perforated tray is that the holes act as **vents for excess material**. However, the drawback is that material seepage may elicit a **gagging reflex**.

Inter-arch vs intra-arch: Full or **intra-arch trays** are essential for removable, and preferred for fixed, prosthodontics. In some countries, there is a penchant for using **inter-arch trays**, which simultaneously act as a bite registration. While this may be useful for single units, the **disadvantages** include ensuring complete closure in centric occlusion, distortion of the delicate 'triple tray' (plastic variety), inability to assess jaw excursions, and technically challenging laboratory procedures.

Tray adhesive

The function of a **tray adhesive** is to prevent material lifting off the tray and causing mass discrepancies. The tray adhesive should be compatible with the given impression material, i.e. alginate, PVS or polyether. Furthermore, to ensure efficacy of the adhesive, it should be applied and allowed to dry before making an impression.

Material manipulation

Most contemporary materials are available in cartridges for automatic **electronic mixing units** or **auto-mixing** hand-held dispensers. **Manual mixing** is almost redundant due to infection control concerns, heterogeneous mix, inadequate mixture of base and catalyst, and the introduction of porosity. **Temperature** was often used with older generations of materials to manipulate the **setting time** and **alter viscosity**. However, these practices alter the chemical composition of the material, and result in erratic setting reactions. Furthermore, newer materials are available in a range of setting times and viscosities, obviating the need to use heat or cold to alter the physical properties. One of the drawbacks of **PVS** materials is that their setting reactions are affected by **latex**. Therefore, handing PVS should be limited to non-latex or polyethylene gloves. Also, complete setting of most elastomers is affected by residual **acrylic monomer** of some provisional restorative materials, but is **unaffected by haemostatic agents** used for gingival retraction.

Undercuts

Undercuts present a problem and may be present due to:

- **Inadequate tooth preparation**;
- **Interproximal gingival embrasures (black triangles)**;
- **Deep sulci**;
- **Atrophic alveolar ridges**, **e.g. pontic sites**;
- **Malaligned teeth**.

Most softer varieties of elastomer are sufficiently flexible to overcome minor discrepancies, but blatant and profound undercuts should be blocked beforehand with wax to avoid locking of the impression tray on the teeth or tearing the material at crucial areas such as finish lines.

Moisture control

Moisture control involves controlling **salivary flow**, **intracrevicular fluid** and **gingival haemorrhage**. The former is by using salivary ejectors and high volume aspiration, while the latter is by soft tissue management (discussed in Chapter 41). An arid environment is essential for recording subgingival margins using **hydrophobic impressions materials**, e.g. PVS. Some PVS impression material can be pre-treated with **surfactants** or topical agents to encourage hydrophilicity.

Single and two stages

The most commonly practised protocol is the **putty-wash** technique, either single-stage or two-stage:

- **Single-stage**: the tray is loaded with a heavy-body material while a light-body wash is simultaneously dispensed onto the prepared abutment(s). The advantage is expediency, but the downside is distortion of the tray and displacement of the soft tissues;
- **Two-stage**: the **first stage** involves taking a **heavy-body or putty** impression, either before or after tooth preparation, with or without an appropriate spacer, or using individual tooth copings. The **second stage** is dispensing a light-body wash onto the abutment(s) and relocating the tray with the set putty into the mouth. The rationale is that shrinkage is minimised, since the heavy- and light-body materials set separately, but accurate location of the tray may be challenging.

Recoil

All elastomeric impression materials suffer from **recoil**, which may result in a prosthesis fitting the plaster die, but not the intra-oral abutment. To minimise this effect, the impression material should be allowed to set **passively**, without excessive pressure while holding the tray, and **removed rapidly** once the material(s) have set.

Key points

- Technique and armamentarium determine the accuracy of an impression.
- Factors such as tray selection, tray adhesive, material manipulation, undercuts, moisture control, single-stage or two-stage and passive setting reaction all influence the accuracy of an impression.

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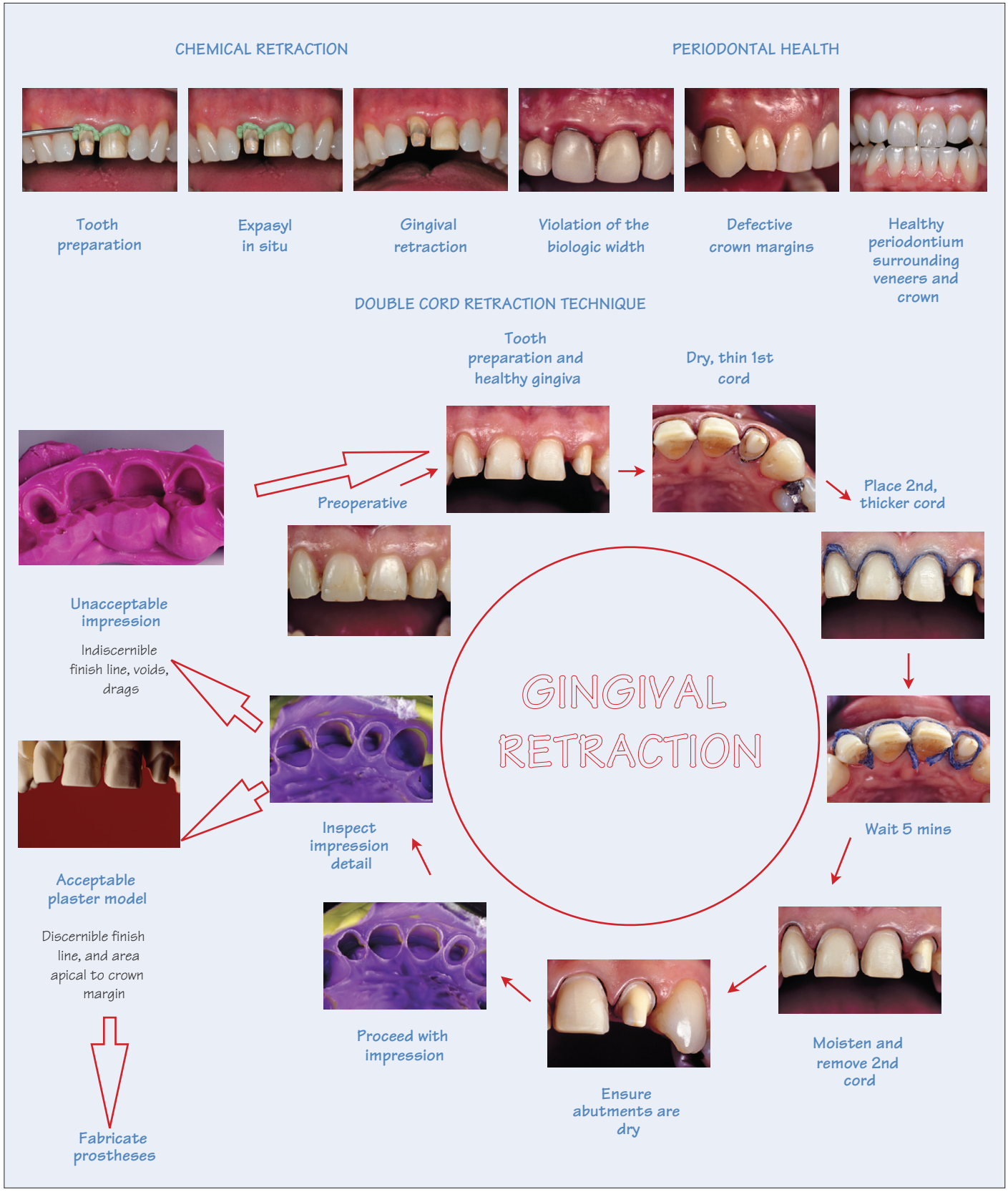
41 Impressions: soft tissue management



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The last factor determining the accuracy of an impression is efficacious **soft tissue management**. This involves a transient displacement (**retraction**) of the circumferential gingivae surrounding the prepared tooth, or implant abutment in order to:

- **Visualise the finish line**;
- **Maintain an arid environment**, particularly for addition silicone (PVS) impression materials;
- **Accommodate a sufficient bulk of intrasulcular impression material** (at least 0.2 mm thickness);
- **Record an area apical to the finish line** to create a correct **emergence profile** of the artificial prosthesis.

The definitive restoration is only as good as the impression. Adequate **soft tissue management** is essential for both **analogue** and **digital** impressions. Apart from the need to choose the appropriate impression material and to use a correct impression technique, most substandard impressions are attributed to ineffective soft tissue control. Soft tissue management can be categorised as, first, **achieving and maintaining periodontal health**, and second, **manipulating the gingivae** to facilitate impression making.

Periodontal health

The **primary determinant** for achieving a successful impression is **achieving and maintaining periodontal health**. A healthy periodontium is a prerequisite for facilitating not only impression making but also subsequent stages such as the try-in and cementation procedures. There are two aspects influencing periodontal health: **patient** and **operator factors**.

The **patient factors** are predominately beyond the patient's and clinician's control, including:

- Genetic predisposition or constitution;
- Age, race, gender, e.g. pregnancy and osteoporosis;
- Systemic illnesses, e.g. diabetes, compromised immune system, psychological stress, bisphosphonate or radiation therapy;
- Dental biotype and bioform;
- Oral pathogens;
- Local trauma or previously compromised vascularity, e.g. periapical lesions;
- Socio-economic status;
- Oral hygiene, local irritants, e.g. smoking, alcohol abuse.

Conversely, the **operator factors** are within the clinician's control, and are remediable with proper techniques, including:

- Oral hygiene, smoking cessation counselling and meticulous prophylaxis;
- Maintaining biologic width integrity;
- Ensuring correct emergence profiles of all provisional and definitive restorations;
- Precision fitting of provisionals to encourage gingival health.

Gingival healing can be as rapid as a few days, or prolonged over several weeks, depending on the prevailing patient factors, or the degree of iatrogenic insult during restorative procedures. Therefore, impressions should be deferred until a **stable and healthy gingival architecture** is evident. This is extremely important for anterior 'pink aesthetics', where erratic gingival contours following gingival recession can be displeasing and may compromise aesthetic outcomes.

Chemical retraction

Chemical retraction is the **least traumatic** method for achieving gingival retraction using hygroscopic gels, usually incorporating **haemostatic agents**, e.g. **Expasyl** (KerrHawe SA, Switzerland). This method is ideal for **equi- or shallow subgingival preparation margins**, where minimal retraction is necessary, but may be challenging for deeper, subgingival finish lines.

Physical retraction

The most predictable and widely practised method for gingival retraction is using **retractions cords**, with or without haemostatic agents. This is the preferred method for **subgingival margins** using either the **single** or **double retraction cord technique**. The potential drawbacks are gingival injury and recession, especially with thin biotypes due to inadvertent trauma during cord placement and removal. If gingival bleeding is present, the cords can be presoaked in **haemostatic agents** such as buffered aluminium chloride, aluminium potassium sulfate or ferric sulfate. Adrenaline is contraindicated due to its undesirable effects of raising heart rate and blood pressure.

Surgical retraction

There are two circumstances when surgical intervention is necessary: first, **gingival hyperplasia**, and second, **violation of the biological width**. Gingival hyperplasia occurs in the presence of open, defective restoration margins, or if a previous restoration has been dislodged for a considerable time. If the preparation margins are approaching the alveolar crest, **surgical crown lengthening** is required for osseous resection to re-establish the biologic width. However, all forms of surgery are **risky with thin biotypes**, with possible **ensuing gingival recession**.

The surgical methods available are:

- **Scalpel** – conventional flap elevation and bone removal is the ideal procedure for crown lengthening, either for aesthetic gingival margin contouring or re-establishing the biologic width;
- **Electrosurgery** – using radio frequencies of greater than 1 MHz, electrosurgery is conducive for gingivectomy, widening of the gingival sulcus and coagulation;
- **Lasers** – e.g. argon, KTP, diode, Nd:YAG and microsecond-pulsed CO_2 lasers have similar functions to electrosurgery and are useful for soft tissue incisions and sulcular debridement;
- **Rotary curettage** – using diamond burs for gingival resection or sulcus widening. However, this is a highly destructive procedure, and the lack of tactile sensation can lead to widespread gingival trauma and prolonged haemorrhage.

Key points

- Proper soft tissue management is essential for facilitating and producing accurate impressions.
- The primary determinant for precise impressions is achieving and maintaining periodontal health.
- Soft tissue manipulation is achieved by a variety of gingival retraction methods including chemical, physical and surgical.
- The choice of retraction method depends on the prevailing clinical situation.

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42 Computer-aided design and manufacture technology

CAD/CAM protocol and fabrication methods

CAPTURE → CAD → CAM → Subtractive / Additive / Combination

APPLICATIONS

Implant abutments

Customised zirconia and titanium abutments

Indirect restorations

Full contour

- Acrylic single and multiple unit provisionals
- Resin-based composite inlays, onlays, veneers and crowns
- Feldspathic and leucite-glass inlays, onlays, veneers and crowns

Partial contour

- Titanium and alloy FPD frameworks
- Lithium disilicate, zirconia, alumina single-unit copings and FPD frameworks

Wax-ups

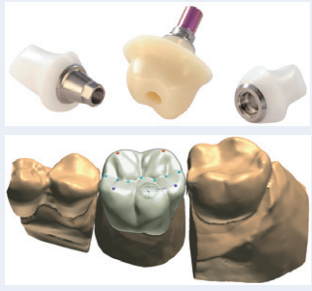
3-D printing technology for creating wax-ups of individual copings or FPD frameworks that can be subsequently scanned for CAM

Models, splints and templates

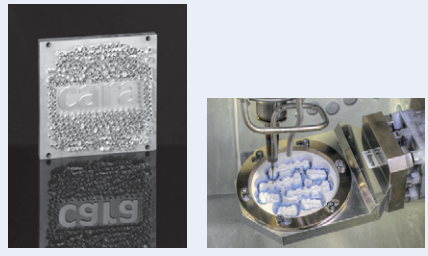
Solid free-form or stereolithographic prototyping for producing resin full arch models, occlusal splints and surgical templates for guided implant placement

Veneering dense ceramic cores

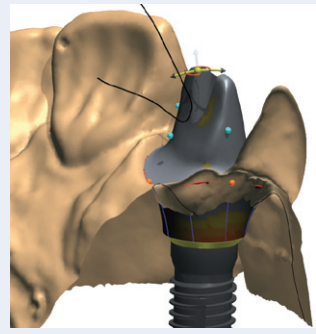
Fully automated production for multilayered strong and aesthetics restoration. High strength dense ceramic cores can be veneered with aesthetic high glass content silica-based ceramics using either direct-write assembly, direct shell production casting or laser sintering



CAD of a single unit coping



CAM of an FPD framework



CAD/CAM implant abutment

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CAD/CAM (computer-aided design and computer aided manufacture) technology is heralding a new age of digital dentistry. CAD/CAM involves three distinct processes: **capture**, **design** and **fabrication**.

Capture

Capture or **digitisation** is converting a 3-D structure into a dataset for creating a virtual representation of an object, e.g. by a **triangulation process**. This is achieved using 3-D scanners, which are either **optical** or **mechanical**. An **optical scanner** uses **white light projections** or **laser beams**, while a **mechanical scanner** uses a **ruby ball** which traverses the object and converts the information into a graphical computer image.

Capture can either be **intra-oral**, i.e. an **optical impression** of the prepared tooth/teeth and full-arch digital impressions, or **anatomical dental duplicate**, e.g. scanning an impression of the tooth preparations, poured plaster dies, or proposed wax-up of the prostheses.

Design

CAD is **designing** a restoration, which is subsequently stored as a **computer file**. At present there is no industry standard file format, and each system is manufacturer-specific and non-interchangeable. Several design processes are possible, including:

- **Extrapolation technique** – the morphology of the restoration is obtained from a software database;
- **Correlation technique** – involves taking two optical impressions, one of the prepared tooth and one of the envisaged occlusal morphology, which can either be a preoperative impression or a scan of a proposed wax-up;
- **Replication** – copying the occlusal anatomy of a similar type of contralateral tooth;
- **Functional technique** – two optical impressions, one of the preparation and the second of a functional generated pathway for designing the occlusal morphology.

Fabrication

CAM is **fabricating** or manufacturing a restoration by converting data from the computer file into a set of commands that are sent to the manufacturing unit, which can be **chair-side** (Cerec® System, Sirona, Germany), in a **dental laboratory** (Everest, Kavo, Germany), or a **centralised production plant** (Cara, Heraeus, Germany). To date, no single system can fabricate all types of restoration using the entire spectrum of restorative dental materials. The prostheses can either be **full contour** (finished by staining, characterisation and/or polishing or glazing), or **partial contour** (coping or framework), which is manually veneered to create full anatomical form. The methods for CAM include:

- **Subtractive method** – milling an ingot to the desired shape;
- **Additive methods**, for example:
  Generative rapid prototyping (3-D printing) for fabricating wax patterns;
  Solid free-form fabrication (stereolithography) for resin full-arch working models or surgical templates for guided implant placement;
  Depositing material onto a die by **selective laser sintering** (e.g. for alumina and zirconia frameworks);
  Direct-write assembly is an evolving technology, based on a rapid prototyping approach to create dense ceramic cores and frameworks without the waste and damage associating with the milling process. It can also be used for veneering dense high-strength ceramic cores with high glass content ceramics, thereby totally automating fabrication of a highly aesthetic restoration;
  Direct shell production casting and **laser sintering** for placing veneering porcelain layers over a dense ceramic core;
- **Combination** of subtractive and additive methods (Procera, Goteburg, Sweden).

Pros and cons

The **advantages** of CAD/CAM fabricated restorations are:

- **Precision fit** – marginal opening of <10–50 µm, eliminating dimensional inaccuracies of laboratory procedures of investing and casting, computer-aided parameters for ensuring accurate design of copings with adequate support for the overlying veneering porcelain, correct FPD connector and pontics dimensions, and bespoke implant abutments;
- **Expedience and predictability** – access to vast biogeneric database for creating occlusal anatomy and implant abutments (virtual wax-up), eliminating human error during onerous laboratory stages, shorter treatment times using chair-side systems, simultaneous implant fixture and abutment placement for immediate loading, and reduced manpower costs;
- **Aesthetic** and **durability** – full anatomical restorations that do not require veneering, e.g. inlays, onlays, veneers and crowns using polychromatic ingots with a variety of materials for specific aesthetic and functional needs;
- **Versatility** – besides indirect provisional and definitive restorations, CAD/CAM technology can also be utilised for surgical templates (stents), customised implant abutments and virtual occlusal relationships of dental arches, which may eventually replace conventional articulators. In addition, various materials including metals, resins and ceramics can be used depending on clinical needs.

The **drawbacks** include:

- **Unforgiving clinical protocols** (precise tooth preparation, excellent tissue management and accurate impressions);
- **Software** and **equipment training**;
- **Limitation** of software and milling devices for complex designs;
- **Poor aesthetics** with monochromatic ingots;
- **Software** and **equipment updates**, involving additional cost and time-consuming training.

Key points

- The CAD/CAM process can be divided into capture, design and fabrication.
- CAD is not limited to providing indirect restorations, but also has numerous applications such as for implant surgical stents.
- CAM can use a wide spectrum of dental restorative materials for fabricating precision fit, durable and aesthetic restorations.
- CAD/CAM is an evolving technology that promises a revolution in many existing clinical and laboratory procedures.

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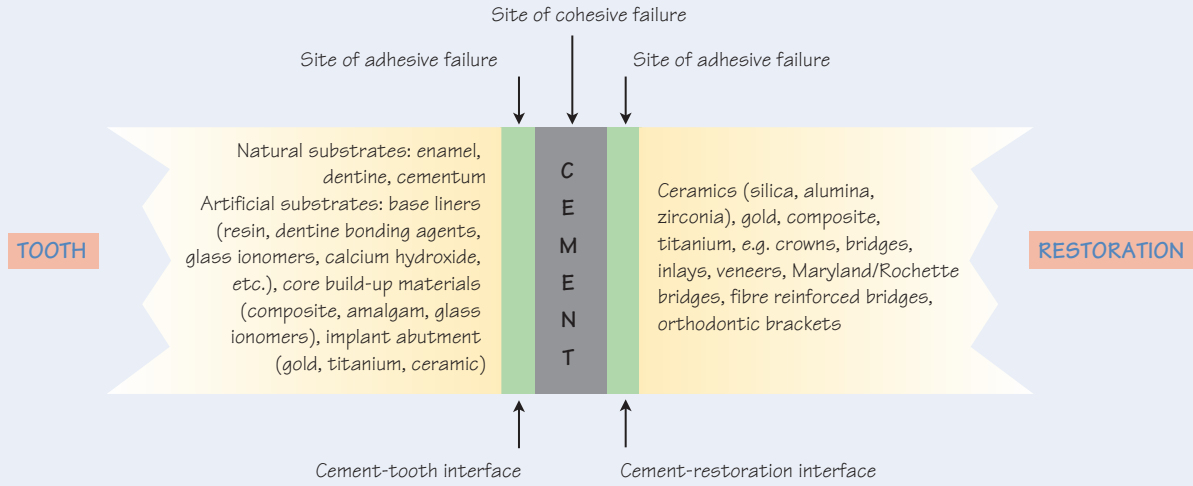
43 Luting agents

INTERFACES

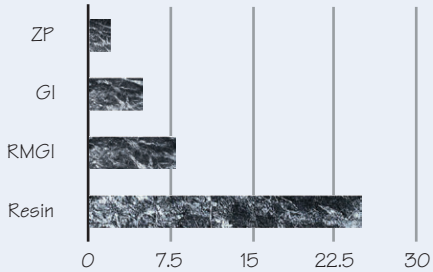


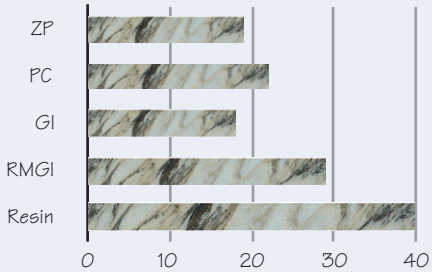
CONVENTIONAL CEMENTS

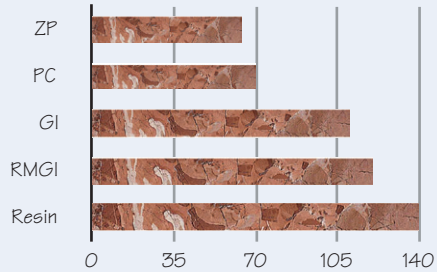
	Liquid	Powder	Advantages	Disadvantages	Luting mechanism: cement-tooth interface	Luting mechanism: cement-restoration interface
Zinc oxide/eugenol (ZOE)	Eugenol, water, acetic acid, zinc acetate, calcium chloride, olive oil	Zinc stearate, zinc acetate, rosin	Palliative, ideal for provisionals, reinforced, EBA (ethyoxybenzoic acid) and super-EBA versions	Low strength, high solubility, brittleness, no antibacterial effect, retards setting of permanent resin-based cements	Mechanical interlocking	Mechanical interlocking
Zinc phosphate (ZP)	Phosphoric acid, aluminum phosphate, water	Zinc oxide, magnesium oxide, silica	Thin film thickness, modified ZP with silicate and fluoride offers improved aesthetics and fluoride release, respectively	High solubility, brittleness, no antibacterial effect, exothermic reaction, initial pH 2 may cause pupal irritation, pH neutralised after 48 h	Mechanical interlocking	Mechanical interlocking
Polycarboxylate (PC)	Polyacrylic acid, carboxylic acids (itaconic acid, maleic acid, tartaric acid), water	Zinc oxide, magnesium oxide, stannous fluoride	Bonds to metal, and tooth calcium ions via carboxyl group, fluoride releasing, low film thickness	High solubility, brittleness, no antibacterial effect, technique sensitive mixing	Chemical adhesion with natural tooth substrate	Mechanical interlocking
Glass ionomer (GI)	Itaconic acid, tartaric acid, maleic acid, water	Zinc oxide, magnesium oxide, calcium aluminum fluorosilicate	Bonds to moist dentine, low film thickness, reduced pupal irritation, fluoride release, pre-capsulated and light-cured versions	Low strength, high opacity (poor aesthetics)	Chemical adhesion with dentine	Mechanical interlocking

Solubility ZOE > PC > ZP and GI >Resin

Pupal irritant Resin and ZP > GI > PC > ZOE







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Luting agents or **cements** are used for retaining indirect restorations on teeth or implant abutments. The functions of a luting agent are:

- **Retention** for preventing dislodgement of the restoration. However, retention alone is insufficient for success. A restoration may be in situ but, if microleakage is present, this may lead to pulpal and gingival irritation, requiring removal of the offending restoration;
- **Hermetic seal** between the tooth and restoration to minimise **microleakage**, prevent secondary caries and pulpal and gingival inflammation. In addition, an efficacious seal retards **dentinal fluid movement**, mitigating hypersensitivity;
- **Resist oral functional** and **parafunctional forces**, which are particularly significant for tooth preparations with inadequate resistance form.

Mechanism

The **cementation mechanism** of cements is classified as:

- **Non-adhesive** or **mechanical interlocking** retention by engaging tooth surface and restoration intaglio surface irregularities, measuring **20–100 µm**. This mechanism is applicable for all dental cements;
- **Micromechanical** 'adhesion' is engaging finer surface irregularities of **<2 µm** created by etching, air abrasion, and usually in combination with a dentine bonding agent (**DBA**), to form a **hybrid layer (0.5–10µm)** – discussed in Chapter 45;
- **Chemical (molecular) adhesion** by **bipolar**, **Van der Waals forces** and **chemical bonds**, which is the ideal adhesion, and contemporary cements strive to achieve this ideal.

Interfaces

The mechanism of retention by cements can broadly be termed **luting** or **bonding**. **Luting provides non-adhesive** retention, while **bonding** implies a closer approximation of the cement with the tooth and restoration, which includes **micromechanical** and **chemical adhesion**.

There are **two interfaces** between **cements** and the **tooth/restoration** complex. On the tooth side, the substrate is either dentine, enamel or cementum, and is called the **cement–tooth interface**. On the opposing side is the artificial restoration, termed the **cement–restoration interface**. Certain **resin cements** in conjunction with **DBAs** offer **chemical adhesion at both interfaces**. A large number of interfaces are created depending on the substrate on the tooth and restoration sides. These interfaces are the weakest link, accounting for **adhesive failure** of the restoration. Conversely, **cohesive failure** occurs due to cement breakdown or fracture within the tooth or the restoration.

A seal is essential to prevent microleakage between the **concealed interfaces** beneath the bulk of the restoration, as well as at the '**open**' **margins** exposed to the oral cavity. Furthermore, the exposed margins are also vulnerable to **occlusal stresses transmitted from the coronal part** of the restoration to the cervical aspect, and the cement should be resilient enough to resist these forces and maintain a long-lasting hermetic seal.

Properties

Most properties of cements are assessed by laboratory tests that are useful for comparison, but not for clinical performance, e.g. zinc phosphate dissolves in experimental tests, but provides long-term retention in clinical practice, impeding toxins and preventing dentinal fluid flow. Also, the methodologies of various studies are rarely identical, making a judicious comparison very difficult. The favourable properties of a dental cement should include:

- **Physical** – similar elastic modulus, shade and optical properties to natural teeth, and provide thermal insulation;
- **Mechanical** – high compressive, fatigue, tensile and shear bond strengths (**SBS**), and promoting increased fracture resistance of restoration and the supporting abutment;
- **Chemical** – insoluble in oral fluids and resisting water sorption;
- **Biological** – biocompatible with dental and surrounding soft tissues, bacteriostatic and/or bactericidal, bio-regenerative (fluoride releasing);
- **Minimum film thickness** – **25 µm** is often quoted as an ideal, but realistic in vivo values vary from **50 µm to 350 µm**;
- **Radiopaque**;
- **Aesthetic**;
- **Handling properties** – ease of mixing or dispensing, sufficient working time, rapid setting time, adequate fluidity for thin film thickness.

Classification

Dental cements can broadly be classified into **conventional** (zinc oxide/eugenol, zinc phosphate, polycarboxylate, glass ionomer) and **contemporary** (resin and resin-modified glass ionomers – discussed in Chapter 44).

All dental cements consist of a **matrix** infiltrated by **filler particles** to confer favourable properties. The salient properties of some popular **conventional cements** are as follows:

- **Zinc oxide/eugenol** (discussed in Chapter 38) – palliative temporary cement used for provisionals, but caution is necessary when using a subsequent definitive resin cement since eugenol is a radical scavenger, possibly retarding polymerisation of resin-based luting agents;
- **Zinc phosphate (ZP)** – the first permanent cement, introduced in the 1920s, and was the gold standard for nearly half a century. ZP offers good mechanical properties, but poor marginal seal due to dissolution in oral fluids;
- **Polycarboxylate (PC)** – invented in the 1960s, based on ZP, but with the added benefit of being more biocompatible and the ability to bond to tooth substrate and metal. However, the technique-sensitive mixing procedure has made this cement almost redundant;
- **Glass ionomer (GI)** – introduced in the 1970s by Wilson, this polyacrylic acid composition offers chemical adhesion to dentine, fluoride release and a thin film thickness. The drawbacks are poor mechanical properties and unaesthetic opaque appearance, limiting its use to base liners. However, resin-modified glass ionomers (**RMGI**) have overcome many physical and mechanical limitations of GI (discussed in Chapter 44).

Key points

- Luting agents are used to adhere dental restoration to teeth or implants.
- An ideal cement should seal and retain a restoration, as well as resisting oral forces.
- Dental cements can be classified into conventional (ZOE, ZP, PC and GI) and contemporary (resins and RMGI).

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44 Luting agents for definitive restorations

CONTEMPORARY CEMENTS

	Formulation	Varieties	Advantages	Disadvantages	Cementation mechanism: cement–tooth interface	Cementation mechanism: cement–restoration interface
Resin-modified glass ionomer (RMGI)	Polyalkenoic acid with addition of a methacrylate component (e.g. HEMA) and fillers	Pre-capsulated, chemical and light-cured	Adhesion to dentine, thin film thickness, antimicrobial, fluoride releasing, low solubility, adheres to moist tooth substrate, reduced chemical trauma to pulp	Mechanically weaker than resins, significant post-cementation dimensional changes may fracture weak ceramics	Chemical adhesion to dentine	Mechanical interlocking
Conventional resins (CR)	Polymer infiltrated with filler particles	Chemical, light and dual cured, low and high viscosities, shade tints to modify colour	High compressive strength, superior optical properties	Technique-sensitive, hydrolytic degradation, shade shift over time, possible postoperative sensitivity with poor technique	Micromechanical adhesion and/or chemical adhesion	Chemical adhesion
Adhesive resins (AR)	Polymer infiltrated with filler particles with the addition of an adhesive functional phosphate monomer, e.g. MPD (10-methacryloyloxydecyl dihydrogen phosphate)	Dual cured, self-etching, self-adhesive, antibacterial, fluoride releasing	High compressive strength, superior optical properties, chemical bonding to cast metal , alumina and zirconia substructures	Technique-sensitive, hydrolytic degradation, shade shift over time, lower bond strength compared to CR, reduced postoperative sensitivity compared to CR	Micromechanical adhesion and/or chemical adhesion	Chemical adhesion

CHOICE OF DEFINITIVE CEMENTS

Type of restoration	Restorative material	Ideal cement	Possible cement
Cast metal crowns and inlays, intraradicular posts, porcelain fused to metal crowns and fixed partial dentures (bridges)	High gold and semi-precious alloys	AR, RMGI	ZP, PC, CR
Maryland/Rochette bridges and splints	Semi-precious alloys	AR	CRD
Fibre-reinforced composite bridges and splints	Composite, fibre	AR	CRD
Light-transmitting intraradicular posts	Fibre, zirconia	AR	CRD
Orthodontic fixed brackets	Metal alloy	AR	CRD
Inlays and onlays	Composite or silica-based ceramic	AR	CRD
Porcelain laminate veneers (feldspathic)	Silica-based ceramics	CRL	CRD, AR
All-ceramic crowns, e.g. feldspathic, leucite-reinforced pressed glass, lithium disilicate	Silica-based ceramics	CRL	CRD, AR
All-ceramic crowns and fixed partial dentures of glass-infiltrated alumina, densely sintered alumina, zirconia substructures	Alumina- and zirconia-based ceramics	AR, RMGI	-
Implant-supported crowns or fixed partial dentures	Porcelain fused to metal, or alumina- and zirconia-based ceramics	AR, RMGI	ZOE

KEY

AR, adhesive resins; CRL, conventional resin light-cured; CRD, conventional resin dual-cured; PC, polycarboxylate; RMGI, resin-modified glass ionomer; ZOE, zinc/oxide eugenol; ZP, zinc phosphate

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Contemporary cements for definitive restorations can broadly be categorised as **resin-modified glass ionomers (RMGI)** and **resins**. The latter can be further subdivided into **conventional resins (CR)** and **adhesive resins (AR)**.

Resin-modified glass ionomers

RMGIs exploit the benefits of both glass ionomers and resins. The **glass ionomers** bond to dentine, have a thin film thickness, release fluoride and are less prone to ageing degradation, while the **resin** part confers improved physical, mechanical and aesthetic properties. RMGIs are the **most popular luting agents** used in clinical practice due to ease of use, and are less technique-sensitive than resins. The **indications** include cast metal and high-strength ceramic core restorations such as alumina and zirconia for tooth abutments and implant-supported titanium and zirconia abutments.

Conventional resins

Resin cements have a similar chemistry to resin-based composite filling materials. An **organic resin matrix** (e.g. Bis-GMA) is infiltrated with **inorganic filler** (e.g. silica) particles, which are coated with silane to bind with the surrounding polymer (matrix). The **type** and **amount of filler particles** determine the physical, mechanical and optical properties of the cement. The major **advantage** of resins is superior mechanical and optical properties, and they are particularly indicated for bonding **aesthetic ceramic restorations** such as inlays, porcelain laminate veneers and all-ceramic crowns and fixed partial dentures (FPD).

The **adhesion** mechanism at the **cement–tooth interface** of resins is **micromechanical** in conjunction with a dentine bonding agent (**DBA**) by forming a **hybrid layer**. Some DBAs offer **chemical adhesion** by bonding with calcium ions from the hydroxyapatite of the tooth substrate. In order to resist the polymerisation stresses of the overlying resin cement, the **bond strength of the DBA** should be greater than **25 MPa**. The DBA can either be separately applied beforehand, or incorporated within the cement. Caution is necessary with **self-etching DBA** since the **acidic inhibition layer** may be incompatible with the setting reaction of the resin cement. Cement contains **self-etching primers** to eliminate the etching and priming stages, while the **self-adhesive** varieties also contain a bonding agent to simplify clinical protocols. However, the **self-etching/bonding cements** are more efficacious **bonding to dentine than enamel**, but enamel bonding benefits from etching and adhesive application before cementation.

Conventional resins (CR) are recommended for **silica-based** ceramics where aesthetics is a paramount concern. Silica is a **low-strength ceramic (flexural strength 100–300 MPa)** with a **high glass content**, offering increased translucency and superior aesthetics, assuming the underlying tooth substrate is an acceptable colour. In addition, **silica** is amenable to **etching with hydrofluoric acid (HF)** to increase mechanical retention, and when treated with **silane**, creates **silica–silane chemical bonds** at the **cement–restoration interface**. A **separate DBA**, either a **total-etch** or **self-etch** system, is necessary to prepare the tooth substrate before cementation. CR cements are available in a large selection of tooth-coloured shades, enabling accurate colour matching. Furthermore, **try-in pastes** corresponding to the definitive cement shades allow colour assessment and alteration before final cementation.

Adhesive resins

Adhesive resins (AR) have similar chemistry to CR, but with the **addition of an adhesive phosphate monomer**, e.g. MDP (10-methacryloyloxydecyl dihydrogen phosphate) or 4-META (methacryloxyethyl trimellitic anhydride). This allows the cements to have broader applications for cementing cast metal as well as alumina and zirconia core restorations. The latter are classified as **high-strength ceramics** (**flexural strength ranging from 400 MPa to >1000 MPa**), not etchable with HF, and the lower glass content results in increased opacity with poorer optical properties, but greater masking capability for underlying tooth discolouration. The **self-etching**, **self-adhesive AR** are contraindicated for bonding PLVs since their higher pH of 2 is insufficient to **adequately etch enamel** compared to etching with 37% phosphoric acid that has a lower pH of 1.

Choice of cements

The **choice of cement** depends upon the **type of restoration**, the **restorative material** and **prevailing clinical scenario**.

Non-retentive prostheses, such as Maryland/Rochette, fibre-reinforced fixed partial dentures (FPD), porcelain laminate veneers (PLV) and inlays/onlays, rely solely on the cement for retention. Furthermore, **aesthetics** is critical for PLV and ceramic inlays for proper shade matching. In both these circumstances, **resin cements** are ideal candidates, offering superior adhesion and enhanced aesthetics.

The basic rule when using **porcelain** in the oral cavity is that it must be supported. The major concern with **porcelain** is its inherent brittleness (**high modulus of elasticity**), making it vulnerable to fractures. **Fractures** in the hostile oral cavity are caused by the **aqueous environment** and physiological and pathological **occlusal stresses**. The weaker-strength materials such as **silica-based ceramics** must therefore be supported by the natural underlying tooth substrate. Alternately, instead of gaining support from tooth substrate, a **weak silica ceramic** can be **supported by a dense core or substructure**, which can either be metal (PFM) or ceramic, e.g. **alumina or zirconia ceramics**. Therefore, the later can be **bonded** with resin cements, or **luted** with other cements such as RMGI.

Lastly, the **clinical scenario** dictates the choice of cement. If the **resistance** and **retention form** of the tooth abutment is **less** than the **ideal of 4° axial tapers (8° convergence angle)**, a resin cement is a prudent choice. Similarly, **poor marginal integrity** of the restoration may be sealed by resins, if a remake is unpractical. Finally, for deep **subgingival margins**, an arid environment is challenging, and a RMGI that is less sensitive to moisture is a better choice.

Key points

- Contemporary definitive cements can be categorised as resin-modified glass ionomers (RMGI), conventional resins (CR) and adhesive resins (AR).
- The choice of cement depends on the type of restoration, restorative material and prevailing clinical scenario.
- The newer class of self-etching, self-adhesive resin cements simplifies the exacting clinical protocols associated with resin cements.

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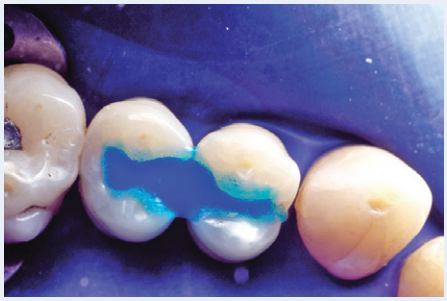
45 Dentine bonding agents

BONDING MECHANISM



Step 1 Conditioning

Enamel and dentine conditioning is usually carried out by 37% phosphoric acid for 20 seconds. On enamel, the prisms are etched, especially uncut, aprismatic enamel to increase the surface area for micro-mechanical inter-locking. On dentine, the smear layer and the organic matrix are either removed or dissolved

Step 2 Priming

Solvents carry monomers to create a transient hydrophobic environment for the subsequent step of adhesive application

Step 3 Bonding

The adhesive is usually an unfilled resin that seals the exposed dentine tubules, and forms a resin-collagen complex termed the hybrid layer. Also, above the hybrid layer is an adhesive layer, which 'links' to the resin-based restorative material

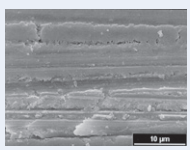
Solvents

	Water	Ethanol	Acetone
Boiling point	100°C	78.5°C	56.5°C
Rehydrates collagen fibres	Yes	Partially	No
Facilitate resin penetration	No	Partially	Yes
Require moist dentine	No	Partially	Yes
Technique sensitive	Low	Intermediate	High

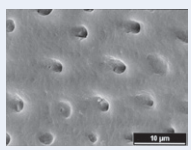
Comparison of total etching and self-etching agents

	Total etching	Self-etching
Etchant pH	≈1	≈ 2
Etching pattern	Profound	Shallow (especially on enamel)
Smear layer and dentine inorganic phase	Removed	Dissolved and incorporated into the hybrid layer
Hybrid layer thickness	Thicker	Thinner
Technique-sensitive	High	Expedient, but concerns about enamel etch pattern
SBS	Usually stronger than SE systems, comparable to enamel bond	Dentine bond is erratic, can be stronger than enamel bond. Aprismatic (uncut) enamel requires prior etching with phosphoric acid

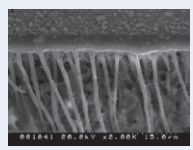
CLINICAL APPLICATIONS OF DBA



Smear layer



Etched dentine



Hybrid layer

Desensitising

IDS

Resin filling

Luting crowns

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Resin-based composite fillings materials and cements require an intermediary adhesive to adhere to enamel and dentine. These adhesives are termed **dentine bonding agents (DBA)**.

Historical background

In 1955, Buonocore introduced the **acid etch technique** for adhering acrylic restoratives to tooth substrate. While **bonding to enamel** has changed little since its inception more than half a century ago, **bonding to dentine** has proved far more elusive, undergoing enormous changes. Scientific research has yielded a better understanding of bonding to dentine, resulting in many generations of DBAs over the last six decades. The breakthrough for dentine bonding came in the mid-1980s with the **4th and 5th generations** of DBAs, with the state-of-the-art **7th generation** introduced in the last ten years.

Bonding to tooth substrate

Bonding to enamel and dentine are fundamentally different processes. For achieving a bond to tooth, the prerequisites are an **inorganic** and **hydrophobic** environment. **Enamel** is nearly **90% inorganic** with little water content and therefore conducive for a successful and predictable bond by **micromechanical interlocking** with exposed **enamel prisms**. On the other hand, **dentine** is **45% inorganic**, **30% organic** and **25% water**. Consequently, bonding to dentine with a higher organic and **hydrophilic** environment is far more challenging.

Dentine bonding mechanism

Dentine bonding is primarily **micromechanical adhesion**, as opposed to true **chemical adhesion**. However, **some newer DBAs** claim **true chemical adhesion** with tooth substrate. There are **three distinct processes** for achieving a dentine bond using DBAs:

- **Conditioning** the dentine with an etchant (usually 37% phosphoric acid) to remove or dissolve the **smear layer** and **inorganic phase**, exposing **dentine tubules** and **collagen fibres**;
- **Priming** with **monomers** (e.g. HEMA, PENTA or 4-META) to create a transient hydrophobic environment;
- **Impregnation** and **penetration** of an **adhesive resin** (e.g. bis-GMA, UDMA), to encapsulate and stabilise the collagen fibres and seal the dentine tubules by forming a **resin–collagen complex** termed the **hybrid layer** (also known as an **inter-diffusion zone** or **resin-infiltrated dentine layer**).

The thickness of the hybrid layer can vary from **0.5 µm to 10 µm**. However, the **thickness and morphology** of the hybrid layer seems less important than its **consistency** and **integrity** (**lack of gaps**, **porosity and voids**), which are paramount for achieving efficacious and durable dentine sealing and bonding.

The **solvents** in the DBAs carry the monomers that are essential for an efficacious bond. After the inorganic phase is disrupted, the **collagen fibres are unsupported** and, if not sufficiently erected, collapse and leave little room for the subsequent adhesive resin. Therefore, the **function of the solvents** is to **rehydrate** collapsed collagen fibres as well as to create a **transient hydrophobic environment** by removing excess water for the subsequent penetration of the adhesive resin. Numerous agents such as **water**, **acetone** and **ethanol** have been used with varying success. Furthermore, many formulations of DBAs use a **combination** of these solvents to exploit the beneficial properties of each material.

Contemporary DBAs

Current DBAs can be categorised as **total etching (TE)** or **self-etching (SE)**. With TE varieties, **precursory etching** of both dentine and enamel is followed by application of the primer and adhesive. The SE variety does not require etching, since all three stages of **etching**, **priming and bonding are performed simultaneously**. The salient difference between the two systems is that, with TE, the **smear layer and inorganic phase of dentine are removed**, while with SE the smear layer is **incorporated into the hybrid layer**. A major **disadvantage of SE agents** is that the bond to dentine may be superior than to enamel, since the pH of SE is higher than conventional phosphoric acid, and the enamel etching pattern is insufficient for an efficacious bond. At present, **research is inconclusive** as to which system is more efficacious or longer lasting. However, the **advantages of the SE agents** are:

- Less technique-sensitive;
- Degree of dentine moisture not a concern;
- Depth of etching and adhesive penetration into dentine are similar since both processes occur simultaneously, which may allay concerns about depth of resin penetration, and mitigate postoperative sensitivity.

Efficacy

The efficacy of a DBA is assessed by the **shear bond strength (SBS)** and **marginal gap** formation at the restoration–tooth interface. The SBS of the bonding agent should be sufficient to counteract the **polymerisation stresses** generated by the resin-based restorative material and, therefore, prevent breakdown of the bond. The gold standard for SBS comparison is the bond to **enamel**, ranging from **23 MPa to 25 MPa**. **Dentine SBS** are erratic, ranging from as little as **3 MPa to 25 MPa**. The reported **marginal gap** ranges from **zero** to **10 µm**, and minimising this gap is crucial for the success and longevity of the restoration.

Failure of the DBA is multi-factorial, depending on both the **material properties** and **clinical techniques** (adequate isolation, preparation design, mode of light curing, etc.). Marginal gap formation can result in:

- **Secondary caries** – depending on prevailing risk factors;
- **Pulpal pathologies** – in deeper cavities;
- **Discolouration** of tooth, filling and filling margins;
- **Deterioration** of the filling material.

Clinical applications

DBAs are used for nearly all resin-based esthetic dentitry (RED) and many prosthodontic & restorative protocols including:

- **Desensitising**, e.g. following tooth wear (erosion, abrasion, attrition and abfraction);
- **Sealing and disinfecting** following decay removal or tooth preparation;
- **Bonding** direct resin-based composite and amalgam fillings;
- **Luting** intraradicular supports (posts), and most indirect restorations (crowns, PLVs, inlays, FPDs, etc.).

Key points

- DBAs are unfilled adhesives used for bonding restorative materials to natural tooth substrate.
- Enamel bonding is more predictable and preferred compared to dentine bonding.
- Currently two DBAs are available: TE and SE agents.

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46 Luting techniques

PRE-TREATMENT OF INTRA-ORAL ABUTMENT SURFACES

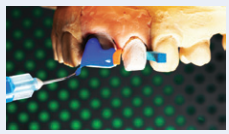
Cement/abutment surface	RMGI	CR + 2–3 step DBA	CR + self-etching DBA	AR
Enamel	None	Phosphoric acid	Phosphoric acid	Phosphoric acid
Dentine	None	Phosphoric acid	None	None

PRE-TREATMENT OF INTAGLIO SURFACES

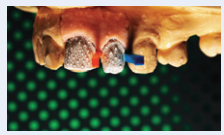
Restorative material	High gold content alloy	Base or semi-precious alloy	Composite/ amalgam	Silica ceramics	Alumina ceramics	Zirconia ceramics
Pre-treatment of intaglio surface	Air abrasion + alloy primer (or tin plate or silica/silane coat) + 37% phosphoric acid	Air abrasion + 37% phosphoric acid	Air abrasion + 37% phosphoric acid + silane	4–10 % hydrofluoric acid (for etching) + silane	4–10 % hydrofluoric or 37% phosphoric acid (for cleansing)	4–10 % hydrofluoric or 37% phosphoric acid (for cleansing)

Clinical cementation procedure using conventional resin cement

Isolate abutments with cord and wedges



Etch

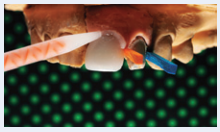


Rinse and dry

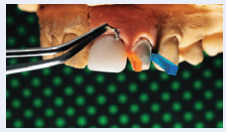
Apply DBA

Seat and mop cement

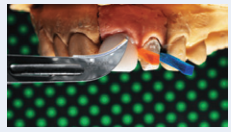
Floss contact points



Try-in paste to stop formation of the oxygen inhibition layer

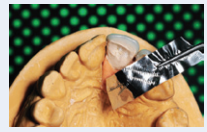


Remove cord and light cure

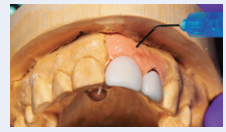


Trim with #12 blade

Polish, e.g. with EVA tips



Check occlusion



Irrigate with 0.2% chlorhexidine

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The performance of any cement depends on **clinical factors**, **pre-treatment** of the indirect restoration **intaglio surface**, and the **intra-oral abutment**. The cementation technique is both time-consuming and exacting, and any omissions will compromise the durability and long-term survival of the restoration.

Clinical factors

Clinical performance of cements is influenced by:

- **Operator variables** – mixing, dispensing and loading cement, accounting for more than **50% of all risk factors**;
- **Tooth preparation design** – ideal 8° convergence angle and adequate resistance form;
- **Material properties** – accounting for approximately 5% of risk factors;
- **Location of tooth** – anterior or posterior;
- **Patient factors** – oral hygiene.

Pre-treatment of intra-oral abutment

Pre-conditioning of the intra-oral abutment starts by removing the temporary cement, which is accomplished mechanically using hand instruments, rotraty plastic burs (OptiClean, KerrHawe SA, Switzerland) air abrasion, pumice paste or ultrasonic devices. Total removal is essential to avoid compromising the **bond strength** between the **natural tooth substrate** (or **artificial abutment**, e.g. intraradicular post/cores or implant abutments) and the **definitive cement**.

The next stage is **isolation**, either with rubber dam or intrasulcular gingival retraction cords. An arid environment is essential for resin-based cements, but less critical for RMGI. **Rubber dam** is the ideal choice for cementing inlays in posterior teeth, but is unsuitable for anterior teeth since the retaining metal clamps can potentially traumatise the gingival margin, leading to recession, especially on anterior teeth with thin periodontal biotypes. **Gingival retraction cord**, dry or impregnated with an astringent, not only allows visualisation of the abutment margins, but also acts as a physical barrier to avoid excess cement entering the delicate gingival sulcus. However, retraction **cord may be inappropriate** around the implant abutments since the latter can damage the friable epithelial attachment.

Tooth abutment pre-treatment depends on the type of cement being used. If **RMGI** is employed, **no further conditioning is necessary**, irrespective of whether the abutment is dentine, enamel or artificial restorative material, e.g. a composite, amalgam, cast metal and ceramic core, or titanium, alumina and zirconia implant abutments. If a **conventional resin (CR)** is chosen and the abutment is natural tooth substrate, a **total-etch technique** (5th-generation DBA) is recommended to simultaneously etch both the dentine and enamel, followed by application of the primer and adhesive. If a **self-etching (SE) DBA** or **adhesive resin (AR)** is chosen, it is prudent to etch enamel (to create an adequate etching pattern, especially with uncut, aprismatic enamel), **but not dentine**. The reason not to etch dentine is that with SE DBA the penetration of the adhesive resin into etched dentine tubules is reduced, resulting in a weaker bond and possible postoperative sensitivity.

For **artificial intra-oral abutments**, the pre-treatment depends on the restorative material, e.g. for **composite and amalgam core build-ups**, the pre-treatment is air abrasion followed by etching with phosphoric acid.

Pre-treatment of intaglio surface

The conditioning of the fitting, or **intaglio surface**, depends on the restorative material and the choice of cement (RMGI, CR or AR). The methods available are:

- **Mechanical**: rotary diamond burs, only indicated for cast metal surfaces;
- **Air abrasion**: aluminium oxide powder (30–50 µm Al_2O_3 powder at 60–100 psi pressure for 2–3 seconds per cm^2). It has been suggested to use this method on high-strength **ceramics** such as alumina and zirconia, but recent research has revealed that air abrasion can **reduce strength by 30%** by forming microscopic cracks that propagate at the fitting surface during function;
- **Chemical**: hydrofluoric acid (**HF**; 4–10% for 3 minutes) for silica-based ceramics, followed by application of warm silane. HF and phosphoric acid cannot etch metal, alumina or zirconia, but are used for cleansing to ensue a contamination-free intaglio surface, especially following air abrasion. Other chemical agents include **alloy primers** or **tin plating** for some cast alloys;
- **Adhesive** – or unfilled resin, can be applied (but not light cured) onto the intaglio surface, irrespective of the type of restorative material if a resin-based definitive cement is used.

Cementation procedure

After pre-treatment of the abutment and intaglio surfaces, the next stage is dispensing the chosen cement. One of the major factors that reduces cement strength is introduction of air into the cement. For example, **10% porosity** can **reduce strength by 55%**. **Porosity** is primarily due to **method of mixing**, **polymerisation shrinkage** during the setting reaction and disintegration due to **fatigue and thermocycling**. For this reason, **auto-mixing dispensers** and **pre-capsulated cartridges** are ideal for a smooth, reduced porosity mix.

For inlays/onlays, Maryland/Rochette, fibre-reinforced bridges and orthodontic brackets, the **cement is placed on the recipient tooth or teeth**. For intraradicular posts, crowns, FPDs and PLV, the cement is **dispensed onto the intaglio surface of the restoration**. The restoration is correctly located and seated with pressure. Excess cement is immediately mopped, and floss is used for the interproximal areas. If a retraction cord is placed beforehand, this is now removed together with excess cement, and the restoration firmly held in place during light curing from all aspects with an appropriate light intensity and duration (20 seconds for halogen lights and 10 seconds for LED lights of 800 mW/cm^2). After setting, a #12 blade is used to trim set excess cement and the margins polished with silicone tips, interproximal diamond strips, and the sulcus irrigated with chlorhexidine to wash out remnants of cement and promote gingival health. Finally, the occlusion is checked and adjusted if necessary.

Key points

- Successful cementation depends on clinical factors, and appropriate pre-treatment of the intra-oral abutment and intaglio surface of the restoration.
- Pre-treatment of both the abutment and intaglio surface is determined by the restorative material and choice of cement.
- The cementation procedure should be executed meticulously for long-term survival of the restoration or prosthesis.

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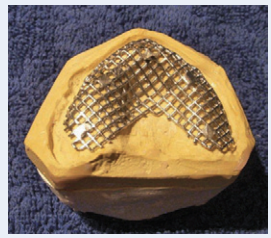
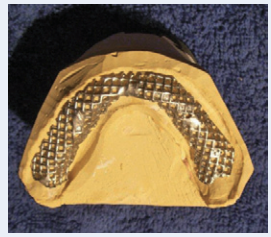
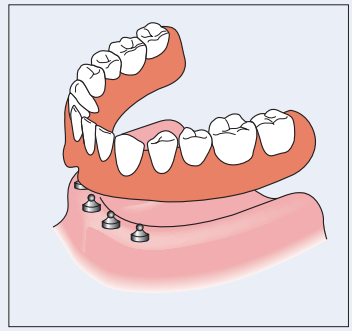
47 Removable prostheses

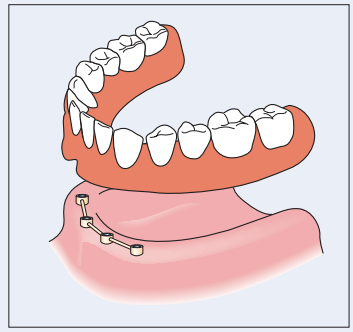




Entirely tissue-borne

Reinforced with metal





Implant-supported overdenture

Removable Full Dentures

- Immediate aesthetic and function following extractions
- Ability to add teeth
- Economical
- Reduced treatment time

Benefits

- Stomatitis
- Poor access for oral hygiene
- Caries
- Periodontal and endodontic lesions
- Tooth mobility
- Poor speech and mastication
- Bone resorption

Complications

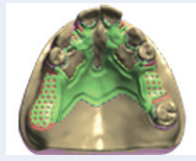
RFD-RPD

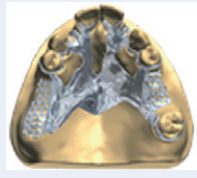
- Temporary prostheses during protracted treatment plan
- Periodontal splinting
- Training bases for assessing function and tolerance
- Surgical template for implants
- Definitive prostheses

Indications

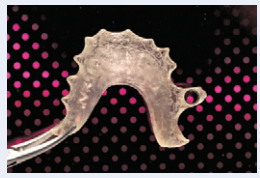
Removable Partial Dentures

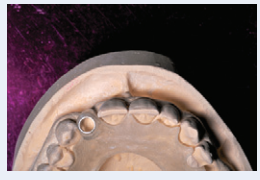
Transitional acrylic denture



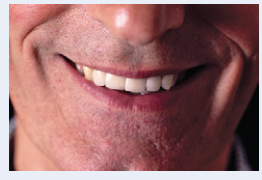


Metal-reinforced framework





CBCT-generated surgical guides



Coloured 'pink' acrylic for soft tissue defects

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Removable dentures are categorised as **full (complete)** or **partial**, and can either be **immediate**, **delayed** or **replacement dentures**.

There has been a significant **decline** in the provision of **exclusively tissue-borne removable dentures** in the last few decades, but an **increase** in **implant-stabilised removable dentures**. The reason is **diminishing clinical knowledge** and **reduced expertise of technicians** (and less experience), and a reluctance to provide removable prostheses when fixed prosthodontic solutions, such as implants, are available for oral rehabilitation. Furthermore, the **success of removable dentures**, especially of totally tissue-supported dentures, relies on **acceptance by the patient** and **tolerance** of the prosthesis, which is often difficult to assess and predict. However, this type of modality is valuable and indispensable in many clinical situations such as **transitional phases** of treatment, or as a **definitive prosthesis** when extensive grafting procedures for implants are contraindicated due to medical history or intra-oral or financial status.

Indications

The indications of **removable prostheses** include:

- **Transitional** full or partial dentures awaiting osseointegration for definitive fixed or removable implant-supported prostheses;
- **Periodontal splints**;
- **Training bases** for assessing altered OVD and anterior guidance;
- **Templates (with radiographic markers)** for preoperative CBCT scans for implant treatment planning;
- **Surgical stents** with drilling holes/sleeves for **guided implant placement** in fully or partially edentulous arches;
- **Definitive oral rehabilitation**.

Edentulism

The sequelae following **tooth extraction** are alveolar **bone loss** and **remodelling**, resulting in:

- **Pseudo class III** and cross-bites of dental ridges;
- **Differential** or **site-specific bone loss**, e.g. flabby anterior maxillary ridge, atrophic mandibular ridge;
- **Prominence of muscle attachments** hindering a denture prescription;
- **Reduced lower third facial height**;
- **Inadequate lip support**;
- **Premature ageing** by formation of facial grooves and fissures;
- **Social embarrassment**;
- **Psychological trauma**.

The above factors contribute to **poor denture support**, **stability**, **retention**, **aesthetics** and **lip support**. Further complications after fitting the denture(s) include **denture stomatitis**, **inappropriate occlusal schemes** (balanced occlusion or balanced articulation), **altered taste sensation**, **painful TMJ** (incorrect OVD), **inadequate freeway space** (2–3 mm advisable), correct **position of maxillary central incisors relative to incisal papilla** (9 mm anterior and 12 mm below), instability due to **incorrect position of posterior teeth**, and continual **ridge resorption** requiring **relines** or **rebases**.

Removable full dentures (RFD)

Edentulous ridges have varied presentation depending on the degree of resorption. For a well-preserved ridge, a denture is merely replacing teeth, while for an atrophic ridge, a denture replaces both the lost bone and teeth. However, full denture success is not only dependent on **ridge morphology**, but also on **patient compliance**. **Retention** of a **maxillary full denture** relies on **suction** from the palatal mucosa, peripheral flanges, tuberosities and a suitable **post-dam**. In contrast, retention of a **mandibular denture** is **more challenging**, depending on the patient's neuromuscular adaptability, extension onto the retromolar and buccal shelves, flanges, denture fixatives, or retention from strategically placed implants or retained roots.

Both upper and lower dentures can be **reinforced** with **chrome-cobalt**, or preferably lighter weight **titanium** for additional strength. This is especially useful for full dentures opposing a natural dentate arch, and for patients with a history of bruxism or fracturing acrylic dentures. In these circumstances, the ridges, flanges and peripheral extensions, including post-dam, are kept in acrylic for future relines. Another risky situation is a removable **full denture against a full fixed arch prosthesis**, which can potentially cause **pressure necrosis** of the opposing edentulous ridge.

Removable partial dentures (RPD)

Before replacing any missing teeth, it is important to consider the **shortened arch concept**, and if functional and aesthetic needs are met, replacing molar teeth is superfluous. If a fixed solution for replacing missing teeth is precluded, a removable prosthodontic alternative should be considered for oral rehabilitation. **RPDs** can be both tissue and tooth/teeth supported. Therefore, all **supporting teeth** require endodontic, periodontal and occlusal assessment. RPDs also offer the **benefits** of the potential to **add future teeth**, or **overdentures** with retained roots (or implants), being relatively **inexpensive**, and **shorter treatment time** compared to fixed options.

Many types of RPDs are possible depending on number and location of the missing teeth, and intended purpose of the removable prosthesis:

- **Total acrylic** bases and teeth are ideal as transitional, training, or templates for scans and fabricating surgical stents. In addition, clasps and rests can be incorporated to improve stability and retention;
- **Metal framework** with acrylic bases and teeth. This variety is suited for long-term usage, and semi-permanent periodontal splinting. **CAD/CAM technology** can be used to design and fabricate partial dentures **frameworks** in a choice of metals such as chrome-cobalt or titanium. In addition, the **design** can incorporate **clasps**, **reciprocating bracing rests**, **milled guiding planes**, **anti-rotational features**, **precision attachments**, and correct paths of **insertion/removal** to cater for numerous clinical situations.

Key points

- Removable prostheses are not an antiquated treatment modality, but have many uses in contemporary prosthodontics.
- The negative aspects of edentulism should be considered before extractions are planned.
- Partial dentures are classified as RFD and RPD, and supported by soft tissues, teeth or implants.
- Both RFD and RPD can be considered as definitive prostheses if implants are contraindicated.

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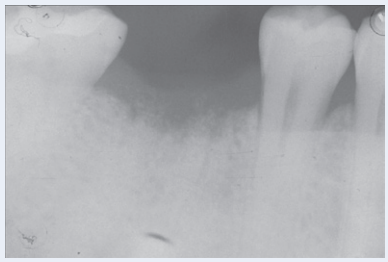
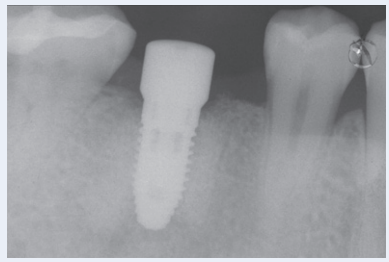
48 Osseointegration

Process	Stimulus	Definition
OSTEOINDUCTION	Bone fracture/trauma	Physiological healing process for bone remodelling
OSTEOCONDUCTION	Osteoconductive material	Bone apposition on surface of foreign material
OSSEOINTEGRATION	Biocompatible material	Structural & functional integration with bone over time



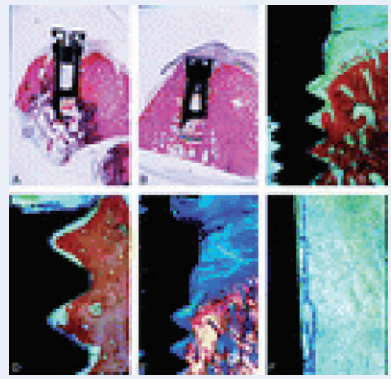
Osteoinduction

Radiograph showing bone repair and remodelling following osseous trauma, e.g after tooth extraction



Osteoconduction

Radiography showing apposition of bone on the surface of a foreign body or material, e.g bone grafting or implant



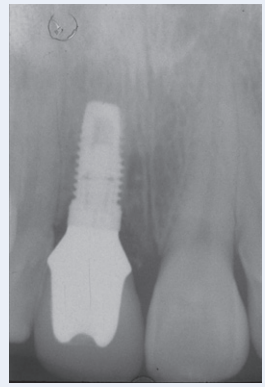
Osseointegration

Photomicrograph showing intimate bone contact with threads of an implant

Clinical assessment of osseointegration

Visual

This is probably the easiest method to check for absence of inflammation and suppuration



Radiographic

Radiograph showing intimate bone contact with implant, without apparent pathology

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Apart from G.V. Black, **P-I. Brånemark** has made the most significant contribution to dentistry in the last century. His invention of **dental implants** has revolutionised the replacement of single teeth, partial edentulous segments and totally edentulous dental arches with both fixed and removable prostheses. Furthermore, implants are also used for providing **anchorage** for **orthodontic**, **orthopaedic** and **orthognathic** movements as part of oral rehabilitation.

Definitions

Three distinct processes describe bone healing and remodelling: **osteoinduction**, **osteoconduction** and **osseointegration**. These three mechanisms are **interrelated** but **not interchangeable**. However, terminology associated with bone growth, remodelling and repair is frequently misused and inaccurate. The definitions for the above are as follows:

- **Osteoinduction** – physiological process of bone healing and repair by **osteogenesis** following traumatic fractures;
- **Osteoconduction** – bone growth on the surface of **osteoconductive** foreign bodies, e.g. implants or synthetic bone grafting materials;
- **Osseointegration** – direct contact of living bone with an implant surface (without formation of fibrous tissue), which is maintained during **functional loading** over a long period.

Processes

The **osteoinduction healing process** is initiated following trauma to bone. **Undifferentiated**, **mesenchymal cells** are converted to preosteoblasts, which are eventually transformed to bone-forming **osteoblasts** and **osteocytes** by stimulation from inductive transformation growth factors such as bone **BMP** (bone morphogenic proteins). This is the normal mechanism that occurs during repair of a bone fracture and implant integration.

Osteoconduction is **bone apposition** on the surface of implants from **pre-existing osteoblasts** or immature mesenchymal cells that have been transformed by the osteoinduction process. The surface of the implant is said to be osteoconductive and promotes, in combination with the trauma of osteotomy, the stimulation of bone growth. Bone remodelling requires sufficient vascularisation and is signalled by bone growth factors such as insulin-like growth factor (**IGF I**, **IGF II**), fibroblast growth factor (**FGF**) and platelet-derived growth factor (**PDGF**). Bone conduction requires highly **biocompatible materials** such as commercially pure titanium or demineralised bone, and is not possible with incompatible materials such as copper or silver.

Osseointegration is a term coined by Brånemark to describe the **structural and functional integration** of implants with surrounding bone. The process of osseointegration is preceded by osteoinduction and osteoconduction, and implies that anchored implants are **functionally maintained over time**. Osteoconduction is short-lived, while osseointegration maintains bone anchorage of the implant over a long period. This was a monumental breakthrough in oral and craniofacial implantology, paving the way for replacing missing or lost teeth with dental implants. Osseointegration is a **histological concept**, involving formation of an amorphous layer measuring 20–40 µm at the bone–implant interface, which has similar density to surrounding bone. The **speed of osseointegration** can be accelerated by **pre-treatment of the titanium implant surface** by roughening, coating with bioaffinity layers such as titanium oxides or hydroxyapatite. Furthermore, **osseoperception** is evident in patients that have implant-supported dental prostheses, i.e. there is sensory feedback from the loaded implant(s), similar to natural teeth.

Clinical assessment

Osseointegration per se is a histological principle that cannot be visualised clinically. However, it is essential to confirm osseointegration and stability of an implant before it can be prosthetically restored. Some methodologies proposed for assessing **clinical osseointegration**, and its subsequent monitoring, are as follows:

- **Visual** – healthy soft tissues around the fixture without inflammation, suppuration or pain;
- **Radiographic** – periapical or panoramic assessment of bone levels around implants, but because the images are 2-D, buccal dehiscences may be concealed. However, 3-D cone beam computed tomography (**CBCT**) or radio-stereo-photogrammetric analysis (**RSA**) techniques offer better evaluation;
- **Percussion** is probably the crudest method, involving tapping the implant with a hand instrument (similar to tapping a tooth suspected of endodontic lesions), and listening to the pitch of the tone. A high pitch indicates implant stability, while a low, dull pitch infers poorly integrated implant fixtures;
- **Periotest** – quantifies implant mobility in response to an electronically controlled translational hammer. However, readings are erratic and highly dependent on position and angulation of the testing instrument;
- **Dynamic modal testing** – using a rotational hammer that produces an electric voltage to plot a force vs time graph for assessing mobility. However, similar to the Periotest, the readings do not measure the implant in its free state and are highly apparatus-dependent;
- **Reverse torque** – a surgical handpiece attached to the implant head applies a reverse torque of 20 N cm to 'remove' the fixture. This test is traumatic and may disrupt healing or lead to failure of an implant that is slow to integrate;
- **Resonance frequency analysis (RFA)** – measures the resonance frequency of implants to assess the healing process. A drawback with this method is that it fails to account for the initial bone quality and density, which greatly influences integration;
- **Impulse testing** – tests an implant in its free state without being encumbered with the testing apparatus. The implant is percussed with a floating calibrated hammer housed in a probe that records the acceleration time history (**ATH**). The latter is translated by a computer using the fast Fourier transform (**FFT**) algorithm. A comparison is made between an ideal graph and the testing graph to ascertain the 'stiffness' of the implant. This test is useful for both unloaded and loaded implants. However, assessing implants with multiple unit FPDs still requires further refinement.

Key points

- Dental implants have revolutionised the replacement of missing teeth.
- Osseointegration is defined as structural and functional integration over time of an implant with the surrounding bone.
- Various clinical tests are available for assessing osseointegration before restoring implant(s) with prosthetic unit(s).

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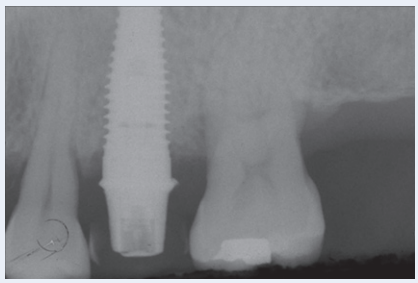
49 Implants: general considerations

Dental implants

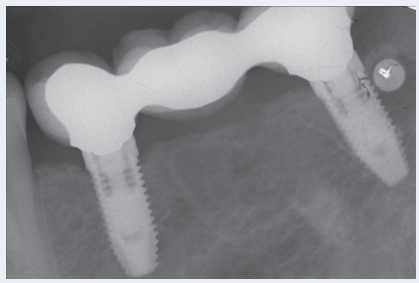
BENEFITS
Restore mastication, speech, aesthetics and support of facial soft tissues
Prevent alveolar bone loss
Prevent destruction of adjacent teeth for FPD
Avoid inflammation of soft tissues and decay of natural teeth, associated with removable prostheses
Predicable treatment modality with good long-term success rates
Versatile treatment options, including single tooth replacement, rehabilitation of partially edentulous and fully edentulous ridges with either fixed or removable prostheses
Choice of a large variety of prosthetic materials including cast alloys, titanium, ceramics and resin-based composites

PRECAUTIONS
Specialist training and liaison with various dental specialists is mandatory
Medical history may complicate surgical procedures
Thorough preoperative dental assessment and treatment planning are key to success
Protracted surgical phases may deter many patients
Costly
Unsuitable for very young and elderly patients
Failure may cause local morbidity, and involve further surgical trauma to rectify problems



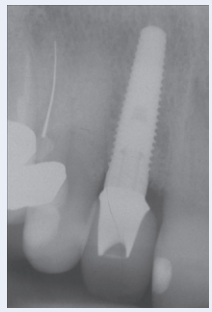
Single tooth

Implant supported crown to replace missing tooth for restoring function without preparing adjacent teeth



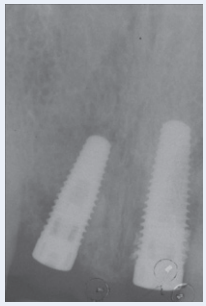
Partially edentulous

A FPD supported by 2 implants



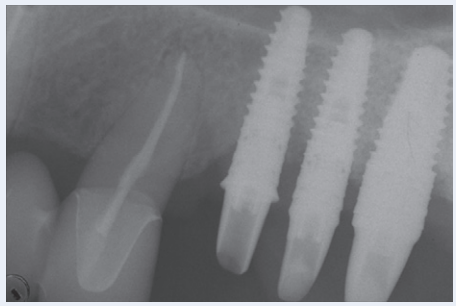
Minimally invasive

Pre- and postoperative radiographs showing excellent bone grafting healing and maintenance following implant therapy



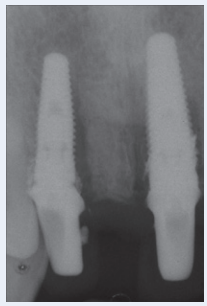
Poor integration

Experience and training is essential for success. Poor positioning and inadequate surgical techniques result in poor osseointegration



Suppuration

Infection and suppuration places implants in precarious situations



Failing implants

Two failing implants in the anterior maxilla due to insufficient bone and lack of preoperative assessment and planning

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Dental implants are increasingly becoming the treatment of choice for missing dentition. Their indications include replacement of **single teeth**, **partially edentulous ridges** and **fully edentulous arches**. Implants are only the beginning of tissue engineering, and future research in **genomics** and **proteomics** will perhaps offer even greater benefits than titanium cylinders for the replacement of missing teeth.

Rationale and indications

Dental implants are no longer an esoteric treatment modality limited to a few specialised practices. The last two decades have witnessed a burgeoning demand for dental implants which is now pervading general dental practices. Furthermore, innumerable studies and controlled clinical trials report encouraging **mean survival rates** of endosseous implants **greater than 90%** over **10 years**, irrespective of the number of teeth replaced or the type of definitive prosthesis. Due to this high level of predicable success, and unlike other dental treatment modalities (both direct and indirect restorations), implant fixtures are potentially placed for a lifetime.

The rationale for implants to replace teeth, compared to tooth-borne fixed or tissue-borne removable prostheses are as follows:

- **Maintenance of alveolar bone** – bone requires stimulation to maintain its form and density. Tooth extraction leads to rapid absorption of the alveolar ridges, resulting in **soft and hard tissue defects**. For example, bone loss in the fully edentulous **maxilla** occurs in a **medial and superior direction**, while in the **mandible** the resorption is **lateral and inferior**. This results in a narrow maxilla, often tending to a class III skeletal relationship;
- **Soft tissue support** – edentulism also results in reduced support for facial soft tissues, causing premature ageing;
- **Improved mastication** – the bite force of implant-supported prostheses is similar to the natural dentition, unlike the reduced masticatory function experienced with removable dentures;
- **Improved phonetics** – because implant prostheses offer better stability compared to soft tissue-borne dentures;
- **Preservation of natural teeth** – in partially edentulous patients, adjacent healthy teeth are spared preparation;
- **Prevention of dental and soft tissue lesions** – both fixed and removable prostheses are potentially harmful to teeth (decay, endodontic and periodontal problems) and the soft tissues (inflammation and continual ridge atrophy). Preventing these unwanted pathologies improves oral comfort;
- **Improved aesthetics** – for both teeth and facial contours due to soft tissue support from implant-supported prostheses;
- **Replacing existing fixed or removable dentures** – a failing FPD with decayed, endodontic or periodontally compromised abutments is potentially ideal for implant therapy. Similarly, loose, uncomfortable dentures (especially mandibular) benefit by implant-supported overdentures, which offer improved mechanical stability, mastication, speech and prevention of further bone loss.

Contraindications

As mentioned above, there is no doubt that many patients can, and do, benefit from implants rather than traditional treatment modalities for oral reconstruction. However, implantology depends on many factors for a successful outcome. Some contraindications that may reduce the chances for optimal prognosis, or preclude patients from implant therapy, are:

- **Medical history** – the following conditions may complicate or delay healing following surgical procedures:
  - Endocrine disorders, e.g. diabetes mellitus, hypothyroidism and adrenal insufficiency;
  - Uncontrolled granulomatous diseases, e.g. tuberculosis and sarcoidosis;
  - Cardiovascular diseases, e.g. angina, aortitis, arteriosclerosis, aortic insufficiency or aneurysms;
  - Bone diseases, e.g. Paget's disease, fibrous dysplasia, histiocytosis X or osteoporosis;
  - Carcinoma, e.g. oral, head or neck;
  - Radiotherapy of the jaws, head or neck;
  - Haematological disorders, e.g. anaemia, haemophilia (factor VIII deficiency), or factor IX, X, XII deficiencies, or reduced platelet count disorders, all predispose to poor haemorrhage control;
  - Autoimmune diseases, e.g. HIV;
  - Medication, e.g. bisphosphonates, immunosuppressant drugs following organ transplants;
  - Other factors, e.g. xerostomia, smoking, pregnancy, psychological stress, poor oral hygiene;
  - Very young and old patients – patients with primary or mixed dentitions are unsuitable candidates for implants, as well as the elderly or infirm, who may prefer non-surgical options;
- **Surgical technique and experience** of the operator influence initial surgical trauma and subsequent successful osseointegration;
- **Dental variables**, e.g. ridge anatomy, adjacent and opposing teeth, occlusal factors, soft tissue morphology;
- **Previous dental history and present dental status**;
- **Skilled multidisciplinary dental specialists** – liaison and successful co-operation with the prosthodontist, oral maxillofacial surgeon, orthodontist and dental ceramist;
- **Duration of treatment** is usually protracted, especially if soft and hard tissue grafting is envisaged. Therefore, the patient should have a degree of patience and endurance to last the course. Furthermore, compliance with oral hygiene procedures and smoking cessation are essential for positive outcomes;
- **Cost** is a major factor in the decision to embark on the implant option. While an implant-retained mandibular overdenture may be within the financial reach of many, a complex and comprehensive fixed oral rehabilitation may be limited to the few;
- **Prognosis** depends on all the above variables, and if unfavourable factors are likely to compromise implant treatment, it may be prudent to seek alternative modalities, rather than commencing a plan that may be fraught with complications and yield unsatisfactory postoperative results.

Key points

- Dental implants are the state-of-the-art treatment modality for replacing missing teeth.
- Implants offer numerous advantages over conventional treatment options for restoring health, function and aesthetics.
- Although successful and predictable, numerous factors affect implant therapy, and contraindications should be thoroughly assessed beforehand.

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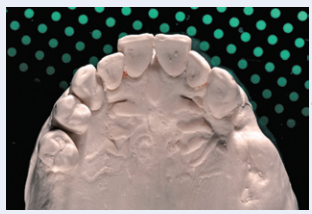
50 Implants: treatment planning

PREOPERATIVE ASSESSMENT

Medical history	Orthodontic	Periodontal biotype	Access for surgery
Restorative	Vital structures	Periodontal bioform	Patient attitude
Periodontal	Vascularity	Keratinised gingiva	Patient compliance
Endodontic	Buccal plate thickness	Interproximal papilla	Risk vs benefit
Occlusal	Bone defect	Aesthetics	Cost
Arch shape	Bone quality	Soft tissue support	Duration of treatment

FAVOURABLE OR RESOLVABLE → Prosthetically driven treatment planning (PDTP) → PDTP

UNFAVOURABLE OR UNRESOLVABLE → Conventional FPD or removable prostheses



Preoperative

Planned extraction of left canine

Wax-up

Surgical guide

PLANNING

Hard tissue augmentation?	Number of implants?	Type of provisionals?
Soft tissue augmentation?	Type of implants?	Osseointegration duration?
Type of surgical protocol?	Fixed prosthetic units?	Anticipated compromises?
	Removable prosthetic units?	

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A patient considering dental implants should initially be assessed using **MAP (medical**, **anatomy**, **prognosis)** as described in Chapter 2. After this cursory evaluation, comprehensive diagnostic tests are essential (discussed in the Diagnostics section) before formulating a treatment plan. The current objective of implant therapy is restoring both function and aesthetics of missing teeth, and the key to achieving this goal is **meticulous diagnosis and treatment planning**.

Preoperative assessment

A detailed **medical** and **dental history** is followed by **diagnostic tests**, including **radiographs**, **CBCT scans**, **photographs**, **diagnostic wax-ups** and **fabrication of surgical guides**. If necessary, **specialist advice** is sought from the periodontist, endodontist, orthodontist, oral and maxillofacial surgeon, radiologist and the dental technician. The **assessment** should consider:

- **Medical history**;
- **Existing dental status** – periodontal, endodontic, and restorative status of existing teeth;
- **Occlusion** – parafunctional activity, occlusal stability (avoiding lateral forces on implant-supported prostheses), and sufficient occlusal clearance for prosthetic units;
- **Arch shape** – narrow, square, oval, crowding, spacing or posterior cross-bite may require preoperative orthodontic treatment;
- **Proximity of vital structures** – sinuses, neurovascular bundles (e.g. inferior dental nerve, mental and incisal foramen) or adjacent tooth roots;
- **Reduced vascularity** – due to previous periapical infections;
- **Buccal plate thickness** or its absence due to fistulas or fenestrations;
- **Extent of bone defect** – following tooth extraction, prevailing or previous periodontal disease, previous surgical trauma;
- **Bone quality** – classified as **types I to IV**; type I is highly dense cortical bone (e.g. in the mandible), and type IV is least dense cancellous bone (e.g. in the posterior maxilla). The **ridge defect** can either be vertical or horizontal, or a combination. For totally edentulous patients, ridge absorption often results in a transformation of class I to class III jaw relationship;
- **Periodontal biotype and bioform** – thin, highly scalloped biotypes predispose to gingival recession, while thick-flat biotypes result in pocket formation following surgical trauma or inflammation. Furthermore, thin-scalloped may also result in defects due to delayed bone remodelling, while thick-flat types result in gingival notches and scarring. **Peri-implant biotypes** around dental implants are also classified as thick and thin, similar to periodontal biotypes;
- **Biologic width** – a histological concept that is the sum of the linear measurements of the **epithelial** and **connective tissues attachments** around natural teeth, averaging 2.04 mm. However, clinically, the **biologic width varies** from as little as **0.59 mm** to **>3 mm** depending on the type of tooth, and no minimum value has been identified as an absolute minimum for gingival health. The biologic width around implants is similar to that for natural teeth but the **implant–epithelium junction is shorter and thinner**, influenced by **implant design**, the presence of **adjacent teeth**, and **platform switching** that shifts the position of the microgap (either in a horizontal or vertical plane) to minimise circumferential bone loss. Differences between natural teeth and implants include that in the former the location of the biological width is **supracrestal**, while in the latter it is **subcrestal**. Also, the **connective tissue fibres** around natural **teeth** are **perpendicular**, but **parallel around implants**;
- **Degree of keratinised gingiva** – a minimum of 3 mm is usually quoted as essential;
- **Interproximal papilla** – for complete **papilla fill** between natural **teeth**, the distance of the contact point to the interproximal bone should be **<5 mm**. However, between two **adjacent implants**, this distance needs to be reduced to a minimum of **3.4 mm** for complete papilla fill. In addition, sufficient interproximal spaces are required for adequate oral hygiene procedures;
- **Aesthetics** – degree of anterior maxillary **tooth exposure at rest**, **relaxed and exaggerated smile**. On average, a relaxed smile shows 75–100% of the maxillary central incisors plus the interproximal papilla. A low lip line shows <75% tooth exposure, while a high lip line shows >75% tooth exposure plus attached gingiva apical to the teeth (gummy smile). Sufficient lip support is also necessary to mitigate labial grooves;
- **Patient's dental literacy and attitude** – counselling about dental preventive measures, tobacco and alcohol abuse, and oral hygiene. Elderly or infirm patients may not be able to tolerate protracted surgical procedures;
- **Other** – **oral cavity access** of a least 35 mm mouth opening at the site of implant placement for adequate surgical instrumentation;
- **Risks vs benefits** assessment and **alternative treatment options**, **cost**, anticipated **treatment duration** and written and verbal informed **consent**.

Prosthetically driven treatment planning

Previously, implant placement was dictated by the surgical approach, i.e. implants were placed according to the existing ridge anatomy. The contemporary approach is **prosthetically driven treatment planning (PDTP)**, i.e. implant placement is dictated by the position of the final restoration(s), and a deficient ridge is augmented accordingly, ensuring that the implant(s) and subsequent restoration(s) are both functional and aesthetic.

The first stage of PDTP is a **diagnostic wax-up** for ascertaining ridge morphology, need for augmentation, number, position, angulation and type of implants (shape, size, surface treatment), the type of prosthetic rehabilitation (fixed, removable, screw- or cement-retained prosthesis). The wax-up also provides a template for any provisional restoration(s), a **surgical guide** (with or without CBCT scans) and a **3-D assessment of ridge anatomy**:

- **Mesial-distal** – minimum 1.5–2 mm distance between implant and tooth and 3–4 mm between implant and implant;
- **Bucco-lingual** – minimum of 1–2 mm on both aspects;
- **Incisal-cervical** – head of implant should be 3 mm apical to the anticipated gingival margin or 3–5 mm apical to the cement-enamel junction of adjacent teeth, and its apex clear of vital structures. In addition, the platform should be aligned for correct emergence profile (<25°) without compromising the occlusion.

Key points

- Implant treatment planning involves meticulous assessment and diagnostic tests.
- Implant placement is prosthetically driven.
- Risk assessment is essential for realistic treatment outcomes and expectations.

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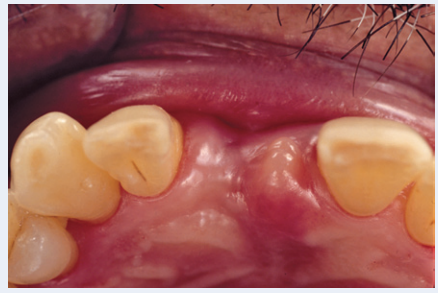
51 Augmentation and site preparation

HARD TISSUE DEFECTS

Siebert's alveolar ridge deficiencies

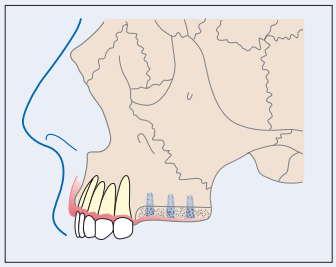
Class I: buccolingual loss with maintenance of apicocoronal height

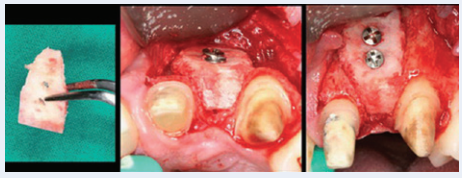
Class II: apicocoronal loss with maintenance of buccolingual width



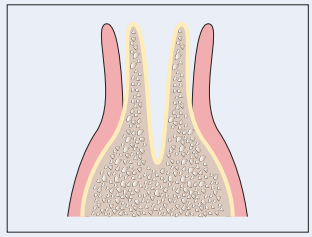
Class III: combination of buccolingual and apicocoronal loss

GRAFTING TECHNIQUES





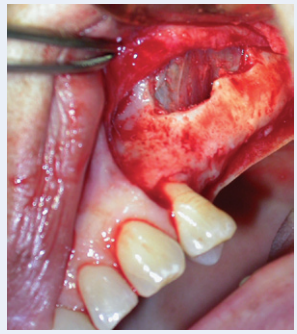
Onlay block



Splint ridge

Socket preservation

Particulate ridge augmentation



Sinus lift

CTG

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The surgical guide of the **prosthetically driven treatment plan (PDTP)** will elucidate whether pre-surgical **augmentation** is required for ideal implant positioning for existing bone and/or soft tissue deficiencies.

Ridge defects

Many criteria have been proposed for classifying ridge defects, for example, the **Siebert for alveolar deficiencies**, and systems based on tooth extraction, for example, the **Meltzer classification**. Ridge defects range from a **pristine ridge** with no resorption, requiring no augmentation, to extensive such as **atrophic ridges** presenting with labial concavities and knife-edge morphologies.

Principles of GTR and GBR

Guided tissue regeneration (**GTR**) is **exclusion** of connective and epithelial tissues in order to **create space** for cells of the periodontal ligament to colonise the root surface. Therefore, in GTR **five components** are involved: **epithelium**, **connective tissue**, **periodontal ligament cells**, **cementum** and **bone**. **Guided bone regeneration** (**GBR**) is similar to GTR, but only **two components** are involved: the **connective tissue** and **bone**. In GBR the competing, non-osteogenic connective tissue is excluded, and a space created to encourage bone formation.

Bone grafting materials

Bone grafting materials offer **structural stability** and **space** for the promotion of osteogenesis. Their **mode of action** can either be **osteoconductive**, acting as a scaffold for new bone regeneration, or **osteoinductive**, i.e. actively stimulating osteoblasts to form new bone. Graft materials can be used in combination to gain advantages of different materials. Examples of bone grafts include:

- **Autogenous grafts** – **osteoinductive** and nonimmunogenic, **harvested from the patient's body**, either **intra-oral sites**, e.g. ramus of the mandible, mandibular symphysis, nasal spine, maxillary tuberosity, zygoma, or **extra-oral sites**, e.g. iliac crest, hip marrow, ribs, cranium and tibial metaphyses. The graft can be **blocks** or **bone scrapings**, including those of the osteotomy for implant placement;
- **Allografts** – bone grafts from another individual, which are freeze-dried, demineralised and irradiated to prevent disease transmission. This avoids morbidity of a donor site, but the graft is less efficacious compared to an autogenous graft;
- **Alloplasts** – **osteoconductive**, derived from inorganic sources such as synthetic calcium hydroxyapatite, calcium carbonate, tricalcium phosphate, alkaline phosphate and bioactive glass, and can be absorbable or non-absorbable, acting as biocompatible fillers without the potential for disease transmission;
- **Xenografts** – cancellous bone from another species such as bovine or porcine that are deproteinised to eliminate the chances of disease transmission, and are available as particulate granules, blocks and collagen plugs. Xenografts are **osteoconductive**, and abundant quantities obviate surgical preparation of donor site(s);
- **Barrier membranes** – usually used in conjunction with particulate grafting materials for providing space and covering grafting materials for enhancing GBR. Membranes can be resorbable (e.g. collagen matrix, polyglycolactic membrane or Vicryl) or non-resorbable (e.g. expanded poly tetrafluorethylene or e-PTFE and titanium reinforced), requiring a second surgical stage for removal;
- **Platelet-rich plasma (PRP)** – accelerates the body's natural postsurgical wound healing by two to three times. PRP is a platelet concentrate from the patient's own blood, containing growth factors such as platelet-derived growth factor and transforming growth factor-beta;
- **Tissue engineering** – the latest and promising method for tissue regeneration by using self-polymerising scaffold structures in extraction or in surgically prepared sites.

Bone grafting techniques

The techniques available include:

- **Onlay block and veneer bone grafts** – utilise autogenous bone blocks that are stabilised with screw fixation onto the residual bone. Veneer grafts are indicated for knife-edge ridges and are more predictable than block grafts;
- **Particulate bone grafting** – the most popular procedure using a variety of grafting materials, which can be mixed together, and covered with membranes, or for extensive augmentation with customised titanium meshes. Indications include horizontal, small vertical defects, socket preservation, sinus lifts and simultaneous grafting with implant placement;
- **Socket preservation** – immediately following tooth extraction for maintaining space and preventing ridge collapse with the Bio-Col technique, using particulate bone and collagen plugs;
- **Sinus floor augmentation (sinus lift)** – indicated for the posterior maxilla for gaining bone volume by lifting the Schneiderian membrane and grafting the floor of the maxillary sinuses. Two techniques are advocated, depending on the amount of residual bone thickness. For **<5 mm vertical bone thickness the lateral wall approach** is preferred, with or without simultaneous implant placement. If the **bone thickness is 7–8 mm**, the osteotome or closed technique is less aggressive, via a crestal incision, avoiding entry into the sinus;
- **Bone expansion** – by decorticalisation (split-ridge technique) with simultaneous implant placement in combination with various types of bone grafts.

Other methods

Other methods for preparing vertically deficient sites include **periodontal growth**, either by **orthodontic extrusion** of teeth destined for extraction for 'gaining' bone by moving the entire dentogingival complex in a coronal direction, or placing fixture devices that are periodically adjusted by the principle of **distraction osteogenesis**. Another method is lateral **repositioning of neurovascular bundles and nerves**, e.g. mental and inferior dental nerves, so that the latter do not impinge on the implant fixtures. However, these procedures can potentially cause paraesthesia and partial or complete anaesthesia.

Soft tissue grafting

Reconstructive **periodontal plastic surgery** is used to compensate or pre-empt gingival recession (especially with thin periodontal biotypes). The most popular method is submucosal and/or free gingival **connective tissue grafts (CTG)** from the palate, anterior to 1st molars or the tuberosities, in combination with coronally advanced flaps. **Membranes** and **silk-gel scaffolds** are a substitute for CTG, avoiding donor site surgery. Soft tissue grafting is more predictable when underlying bone support is present to support the gingival architecture.

Key points

- Augmentation is usually necessary for achieving functional and aesthetic implant therapy.
- Most grafting materials are osteoconductive, acting as scaffolds for new bone formation.
- Both hard and soft tissue grafting may be necessary for site development.

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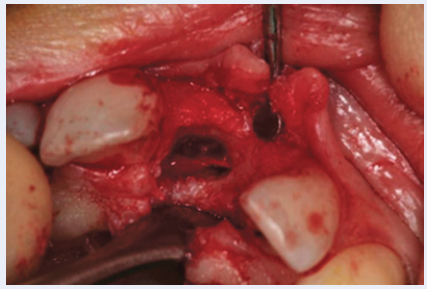
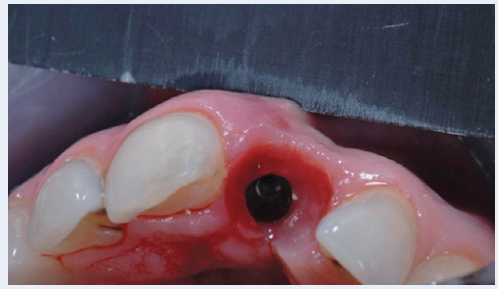
52 Implants: surgical techniques

Preoperative



Osteotomy with flap

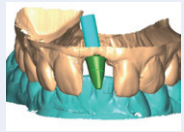


Submerged implant

Two stage procedure showing flap elevation, covering the implant and screw cover with soft tissue to allow osseointegration

Preoperative

One-stage procedure showing flap elevation, and placing a transmucosal healing cap (abutment) to allow osseointegration

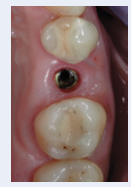


Osteotomy/ flap

Non-submerged

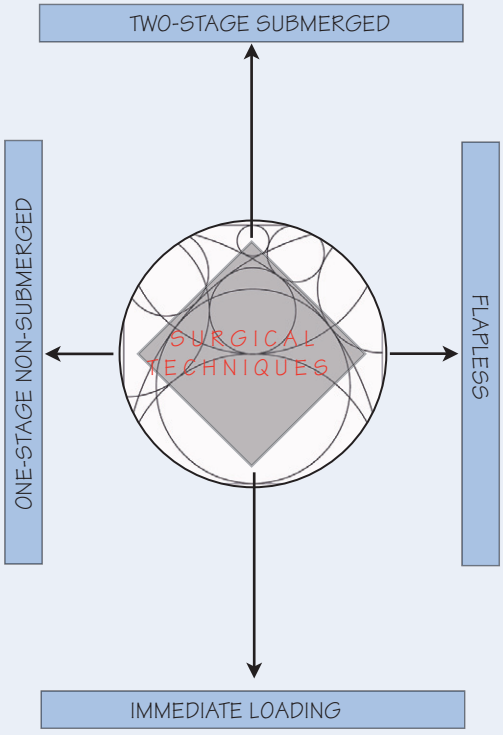
Grafted socket

Healed site



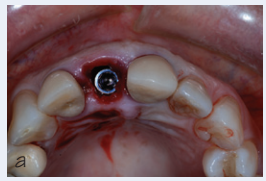
Non-submerged

Flapless surgical stent-guided implant placement



Flapless procedure using a surgical stent for guided implant placement, and immediately loaded with a provisional prosthesis

Preoperative



Osteotomy without flap

Immediate loading

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Surgical techniques have evolved considerably since the Brånemark protocol of distinct surgical and prosthetic phases for the **delayed approach** for implant rehabilitation. Currently, most surgical approaches are guided by a prefabricated **surgical stent**, with or without prior CBCT assessment. The surgical stage involves a **flap** or **flapless** preparation of an osteotomy. The implant is then screwed or tapped into the prepared site to ideally terminal at a supracrestal level, and the implant is either **submerged** by covering with soft tissue, **non-submerged** with a **transmucosal healing abutment**, or **immediately restored** with a provisional restoration.

Flap design

The basic requirement of a flap is that it should be conservative, while allowing adequate access to determine morphology, size and trajectory of the alveolar bone ridge. Several designs are advocated depending on clinical manifestations and include:

- **Full thickness** mucoperiosteal buccal, lingual or crestal incision flaps, with or without vertical releasing incisions, avoiding interproximal papillae if adjacent teeth are present. These flaps are ideal for gaining access, simultaneous bone grafting and osseous contouring;
- **Mini-flaps** are restricted to the area of implantation, e.g. a small buccal flap for single tooth replacement or a **palatal peninsular flap** for avoiding buccal incisions and the ensuing scarring in aesthetically sensitive maxillary anterior regions;
- **Tissue punch** – for exposing underlying bone for 'flapless' surgery. This method is ideal for broad flat ridges, with **adequate attached gingiva**, **not requiring osseous contouring or hard or soft tissue augmentation** at the time of implant insertion.

Flapless design

The **flapless** method is the **least invasive** surgical protocol, but is essentially a blind surgical procedure. The prerequisites for a flapless procedure are **adequate volume of bone** and attached **gingiva**. A surgical stent accurately guides the implant to the pre-designated position without needing to raise a flap. The **fixture head is non-submerged** and a transmucosal healing cap is placed to sculpt the soft tissue and allow maturation. The negative aspect of this protocol is **lack of visualisation** of the bone architecture, particularly if a prior CBCT scan has not been performed. Therefore, a flapless procedure is potentially fraught with the risk of inadvertent **perforations**, especially of thin buccal maxillary plates leading to **fenestrations** and **implant thread exposure**, while **lingual perforation** in the **anterior mandible** may cause **haemorrhage at the floor of the mouth** and impede respiration.

Two-stage – submerged

The **two-stage** or **submerged** delayed approach was originally proposed for stress-free integration of oral implants. It consists of submerging the implant to allow **healing for 3–6 months** (average 3 months for mandible, 6 months for maxilla). Afterwards, the implant is **surgically exposed**, the cover screw removed and the implant prosthetically restored. This method is preferable if primary stability is unattainable, or if extensive pre-surgical or concurrent bone grafting is required.

One-stage – non-submerged

For the **one-stage** or **non-submerged** approach the **cover screw** or **transmucosal healing cap (abutment)** on the implant is exposed to the oral cavity during osseointegration. After a suitable healing period, the cover or cap is removed and the implant restored without needing a second surgical procedure. Furthermore, the clinical success rate for the one-stage procedure is equally effective and predictable as the two-stage approach. Also, a single-stage procedure permits early loading, is patient friendly, reduces postoperative discomfort and is more economical. However, certain criteria must be met, e.g. **no preliminary augmentations** required, greater than **30 N cm primary stability**, an adequate **circumferential zone of keratinised gingival tissue** and **adequate oral hygiene counselling** to prevent and manage **peri-implantitis** and **peri-implant mucositis**, respectively. **Peri-implantitis** is defined as inflammation around an implant causing marginal bone loss, while **peri-implant mucositis** is a reversible inflammatory condition without accompanying bone loss.

Post-extraction placement

Another method for implant insertion is carried out immediately following tooth extraction, which can be **immediate** at time of extraction, **delayed immediate** (2–3 weeks later) or **delayed conventional** (3+ months later). Initial research findings regarding immediate placement and concurrent particulate bone grafting are promising, but long-term trials will need to establish the efficacy of this method.

Immediate loading

In the last few years, **immediate** (<1 week) or **early** (<2 months) **loading** of single and multiple tooth implants has been proposed to expedite the prosthetic rehabilitation phase. After placing the implant(s), a fixed provisional restoration(s) is/are immediately fitted. Immediate loading has also been proposed for immediate post-extraction implant placement in order to reduce treatment times and avoid uncomfortable removable prostheses during the integration stage. The technique is **extremely sensitive**, and preoperative assessment is essential for success. The present research confirms good short- and medium-term survival rates compared to delayed loading (>3 months), but long-term data is currently unavailable. Most of the literature reports **case studies**, rather than **randomised clinical trials (RCT)**, carried out by experienced surgeons under stringent clinical situations on a limited number of patients. The few completed RCTs are inconclusive concerning **peri-implant** or **marginal bone height loss**. The **prerequisites for immediate loading** are:

- **Absence of acute infection** or active suppuration;
- **Adequate vascularisation** of the site, which precludes sites with previous surgical traumas (e.g. apicectomies) or longstanding chronic infection;
- **Good bone quality**, preferably type I or II, e.g. in the mandible;
- **Primary stability >30 N cm**, without **micro-motion (<50–150 µm)** at time of placement;
- **Occlusal loading** is a contentious issue and some authorities distinguish between **immediate provisionalisation** and **immediate loading**. However, it is prudent to avoid undue occlusal stresses during healing, especially in lateral excursions, and in patients with a history of bruxism.

Key points

- Implant placement involves a surgical osteotomy with or without flap elevation.
- Surgical protocols include two-stage submerged, one-stage non-submerged and immediate post-extraction placement.
- Immediate loading is the latest method for expediting the implant prosthetic phase.

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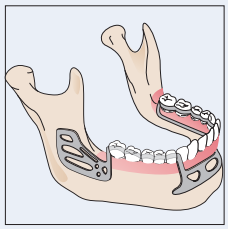
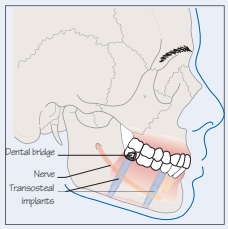
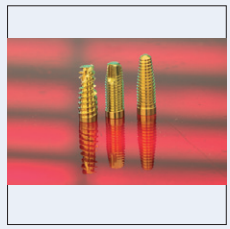
53 Types and configuration of implants



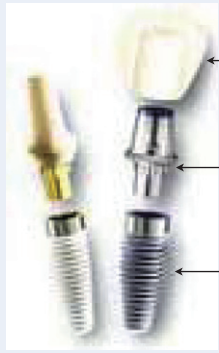
Subperiosteal



Transosseous



Endosseous

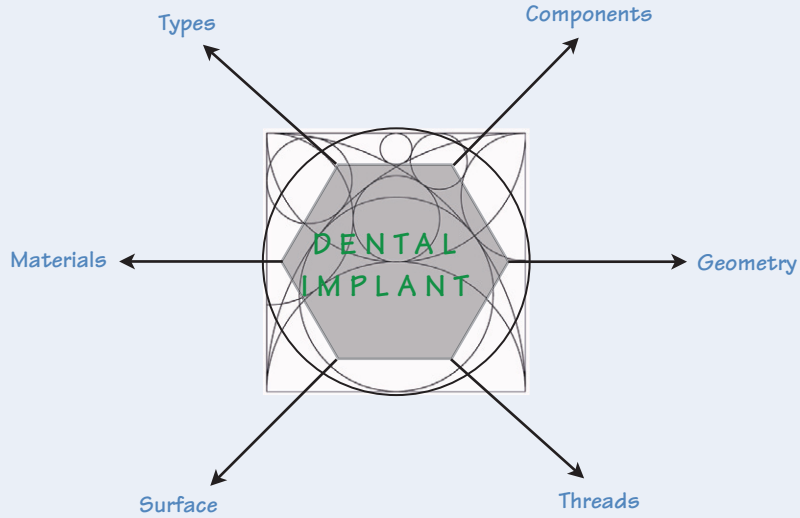


Definitive prostheses, e.g. Single unit crown

Abutment

Endosseous root form fixture

Dental implants can be:
1. Subperiosteal, placed onto bone
2. Transosseous, placed through bone
3. Endosseous, placed into bone, most popular type



The biomaterials from which implants are fabricated include titanium, and more recently, zirconia ceramics

Geometry, including thread pitch, determine primary stability. Most implant profiles are either conical or tapered

The surface modifications of an implant determine secondary stability, reduced healing times especially in low-density bone (Type III and IV)

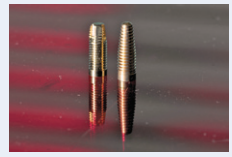
Many thread profiles are available including, V- shaped, reverse buttress, square crest shaped, micro-threads (at implant neck), and macro-threads (on implant body), symmetrical and asymmetrical patterns

Oxidised

Hydroxyapatite

Sintered porous

Micro-threads



Symmetrical

Asymmetrical

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Various criteria are used to **categorise dental implants**, including method of anchorage in bone, number of surgical procedures, materials for fabrication, configuration, type of connection (e.g. internal or external hexagon), dimensions, or the manufacturing company.

Types of dental implants

A dental implant provides **support** or anchorage for an **intra-oral prosthesis**. The basic types of dental implants are:

- **Subperiosteal** – **placed onto the bone**, custom-made for extensively resorbed alveolar ridges, usually involving CBCT scans to extrapolate the alveolar morphology, and using CAD/CAM software a bespoke titanium framework is constructed and surgically placed after flap elevation;
- **Transosseous** – **placed through bone**, usually in the mandible, but due to the extensive surgical protocol, their use today is almost redundant;
- **Endosseous** (**endosteal**) – **placed into bone:**
  Plate or blade form – thin cross-section metal pieces, 65% narrower than root form implants, indicated for narrow ridges not amenable to bone grafting;
  Ramus frame – long metal plates inserted into a resorbed mandible from the chin to ramus;
  Zygomatic – for severely resorbed maxillae;
  Basal (lateral) implants placed via a palatal approach in the maxilla;
  Root form – mimicking the morphology of natural tooth roots, either screwed or pushed (press-fit) into the prepared osteotomy;
  Mini-implants or **small diameter implants (SDIs)** – same as root form but with small diameters (<3 mm). Uses include retaining overdentures, transitional implants for supporting provisional prostheses awaiting integration of larger diameter implants, and orthodontic anchorage.

Virtually all **contemporary dental implants** are **endosseous root form**, and the discussion below is therefore limited to these varieties.

Materials

The material from which a dental implant is manufactured be **biocompatible**, **promote osseointegration** and be **biofunctional** to **resist oral forces** (ranging from 200 N to >2000 N). The materials that meet these objectives are **titanium** and, more recently, **zirconia** ceramics.

Components

Implants are **mechanical modular devices** consisting of:

- **Fixture** – 'root shape' component that is inserted into the alveolar bone, providing foundation for the definitive restoration;
- **Abutment** – intra-oral superstructure that is screwed onto the fixture. The abutments can either be external fitting or internal fitting (see Chapter 54);
- **Definitive restoration** – prosthetic component that is placed onto the abutment, simulating a tooth or teeth;
- **One-piece implants** – the fixture and abutment components are incorporated into one piece, and subsequently restored with a definitive restoration after osseointegration.

The aim of any **implant design** is to maximise bone apposition at the **implant–bone interface** for osseointegration. The configuration of an implant is divided into its **geometry**, which determines **primary stability**, and **surface modifications** at the **interface** that determine **secondary stability**.

Geometry

Geometry refers to **macromorphology** or shape, i.e. 3-D profile, which is usually **conical** or **tapered**. Achieving **primary stability** is a prerequisite for osseointegration and discouraging fibrous tissue formation, and depends on **bone quality**, **surgical technique** and **implant design** (length and platform diameter), surface area, shape and thread profile. For **dense bone, design is less important**, but is **paramount for stability in low-density bone**, e.g. posterior maxilla. The often quoted **minimum length is 10 mm**, but newer, shorter designs have also proven successful. **Tapered** implants are better adapted for immediate placement post-extraction by compressing soft bone for primary stability.

The **function** of **threads** is to **improve primary stability**, **increase surface area** and **translate tensile forces to compressive components** to favour bone preservation. Many thread profiles have been proposed. The **asymmetrical thread** that varies along the length of the fixtures seems better, compared to a **uniform symmetrical** pattern. Also, **rounded threads** reduce peak stresses in bone during implant insertion. Many current implants have **micro-threads** at the neck and **macro-threads**, with altered pitch, along the body for self-tapping and bone compression. The **neck of an implant** requires special attention. Finite element analysis shows that this area has the **highest bone stresses**, causing marginal bone remodelling (**MBR**). An area above the crestal bone of an implant is necessary to form a **biological width**, similar to a natural tooth. Therefore, some designs have a **polished collar** at the neck to allow formation of a biologic width, while others have a **rough neck** to reduce disuse atrophy and retain a greater marginal bone, compared to polished collars.

Surface modifications

Micromorphology modifications of implant surface topography are for promoting and accelerating 'secondary' osseointegration, which predominantly determines **secondary stability**, especially in low-density bone. Some examples include:

- **Machined or polished surface** (Sa: <0.5 microm), originally proposed by Brånemark, but results in reduced bone implant contact compared to roughened surfaces;
- **Macro-irregularities** (Sa: >100 microm), e.g. pores or diffusion-bonded microspheres, and sintered porous surface for bone ingrowth;
- **Micro-irregularities** (Sa: <10 microm) to enhance interlocking of bone at a microscopic level, e.g. roughening by grit blasting, oxidation, acid etching or a combination of these processes;
- **Surface enhancement/coatings** – hydrophilic, hydroxyapatite coating, plasma spray, fluoride-modified surfaces by electrochemical etching to encourage calcium and phosphate deposition, nanotechnology surface modifications, **osteoattraction** for promoting healing by recombinant human growth factors, e.g. morphogenic protein-2.

Key points

- Dental implants are modular devices placed into bone to support teeth.
- Most dental implants are endosseous root forms, made from titanium.
- The geometry of an implant determines its primary stability, while surface modifications determine secondary stability.

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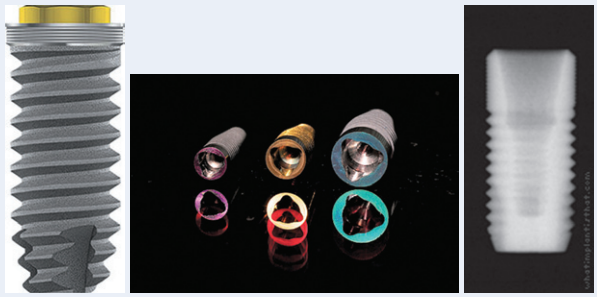
54 Implant abutments

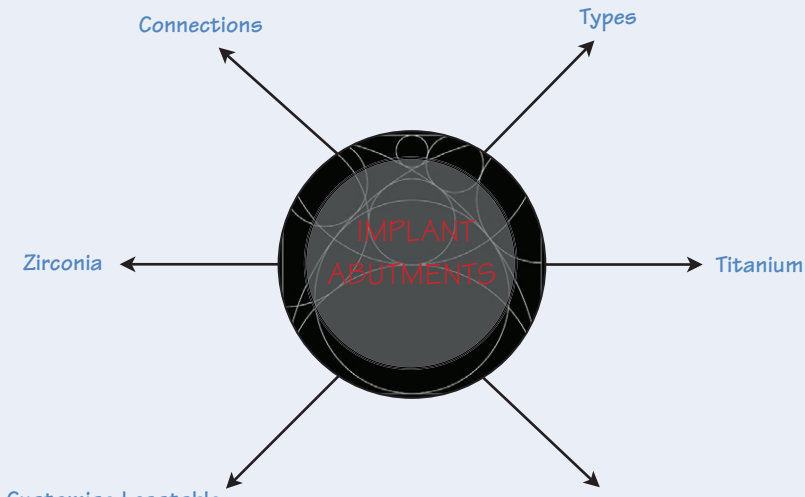


External Internal lobe Conical

All-in-one Separate

Dental abutments are linked to the implants by:
1. Eternal connection, *e.g.* external hex
2. Internal connection, *e.g.* internal tri-lobe
3. Internal connection, *e.g.* Morse taper

Dental abutments can be:
1. One-component, combining abutment and fixture
2. Two-component , separate abutment and fixture

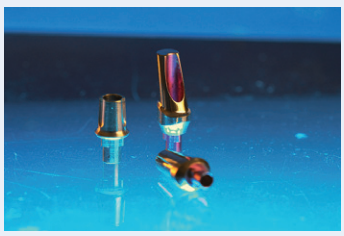


Biocompatible, customisable, high strength, aesthetic, suitable for short-span FPDs, concerns about fracturing, encourage transmucosal epithelial attachment due to smooth surface

Biocompatible, customisable, excellent mechanical properties, ideal for long-span FPD multiple units, compromised aesthetics, encourage transmucosal epithelial attachment due to smooth surface

UCLA-castable gold abutments ideal for misaligned implants, but gold and silica ceramics do not encourage epithelial attachment on abutment due to rough surface

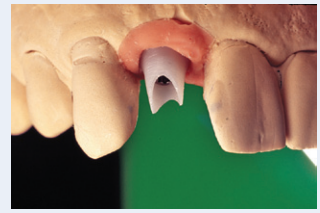
Most popular method for fabricating bespoke abutments fabricated from titanium or zirconia



Stock abutments

Customised gold

Customised titanium



Customised zirconia

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An **implant abutment** provides supports for the definitive intra-oral restoration(s), and the choice is dictated by the type of prosthesis (fixed or removable), location in the mouth, and the material for optimal anterior **aesthetic** and resisting both **external** (functional and parafunctional) and **internal** (preload) **forces**.

Implant abutments are available in two varieties:

- **One-component** – combining the abutment and fixture as an all-in-one implant;
- **Two-component** – separate abutment that is connected onto the fixture head with either a **retaining screw** (usually at a torque of 20 N cm), or **cemented** into place. To prevent abutment screw loosening, some screws are gold-plated for improved retention by creating a bond equivalent to a 'cold weld'. The two-component is the most popular and universal system, offering versatility for **fixture angulation** and numerous **types of abutment** to suit different definitive prostheses. The following discussion is therefore limited to this variety.

Connections

The market is awash with more than twenty different types of implant–abutment connections. It is important that the connection offers **optimal mechanical stability**, **strength**, **fatigue resistance**, **anti-rotation**, **prevent microleakage** and **screw loosening** and provide a **hermetic seal** (minimum **micro-gap**, i.e. butt-joint gap between the abutment and the implant fixture of approximately **2–6 µm**). Currently, no connection (or interface) prevents **bacterial penetration** into the micro-gap. In addition, the clinically acceptable **vertical and horizontal discrepancies** (marginal fit) between the abutment and fixture should be similar to that of the marginal discrepancies between a natural tooth abutment and artificial restoration (approximately +/– 50 µm). Some popular implant/abutment interfaces include:

- **External connection**, e.g. external hexagon (hex), which was the original connection used by Brånemark for screwing a metal substructure for supporting a prosthesis. However, due to its small external height of 0.7 mm, this connection is incapable of withstanding intra-oral forces of individual crowns, and is better suited for connecting multiple implants restored with a fixed partial denture (FPD);
- **Internal connection** – available in a variety of seating depths into fixture (ranging from 1.2 mm to 4 mm), configurations and angles to provide excellent anti-rotational properties, examples include:

  Hexagon (hex) – 6-point retention;

  Internal tri-lobe – 3-point retention;

  Conical interface, e.g. Morse taper and locking taper of <6° internal connection, relying on friction grip and/or screw retention with the strength of a 'cold weld'.

Recent research has suggested that the type of connection, internal or external, has little influence on the stresses and strains transmitted to the bone.

Materials

Implant abutments are fabricated from various materials including **plastic**, **cast gold**, **titanium** and **ceramics**. Plastic copings are inexpensive, and useful for provisional restorations, while awaiting osseointegration. Customised cast gold abutments were popular, but in recent years have been superseded by CAD/CAM customised copings. **Alumina** has the propensity to fracture during preparation and shaping due to relatively poor strength compared to zirconia. Recent research has highlighted that **transmucosal epithelial attachment** on abutments is only possible with **titanium**, **aluminium** or **zirconia** but not with silica ceramics or cast gold. However, **epithelium** will **adhere to any clean and smooth surface**, including cast gold and other restorative materials.

Today, the material of choice for abutments is either **titanium** or **zirconia**. Titanium is unsuitable for aesthetic-sensitive regions, and especially if definitive all-ceramic restorations are planned. Furthermore, **titanium** is a **thermal conductor** and, if exposed at the periphery, may cause marginal bone necrosis in patients who have a habit of ingesting hot drinks. Zirconia is the most promising material that may become ubiquitous for all abutments in the future.

Prefabricated abutments

Prefabricated or **stock abutments** are available in different shapes, heights and predefined angles (10–25°) to accommodate varying **interocclusal clearance** and **implant angulation**. They can be further modified chair-side or in the laboratory, to compensate for implant misalignment. **Platform switching** has been proposed to minimise bone resorption at the neck of the implant fixture. The concept is to use smaller-diameter abutments than the implant fixture head to **shift** the **micro-gap** either in the coronal (**vertical shift**), or mesial (**horizontal shift**) directions to **encourage a soft tissue biologic width**, **discourage bacterial penetration** and thereby prevent marginal bone loss.

Customised castable abutments

Castable UCLA abutments (developed in California) have revolutionised implant abutments, offering flexibility to **compensate for misaligned implant** fixtures by altering abutment angle, taper, finish line and width according to the position and emergence profile of the definitive crown. A plastic tube is trimmed and waxed to the desired shape and position and then cast in gold alloy, with or without a porcelain cervical shoulder margin, to avoid metal shine-through at the transition between the crown and soft tissues.

Customised CAD/CAM abutments

The latest method for customising abutments is using **CAD/CAM** technology to machine **titanium** (with or without electroplated gold) or **ceramics** (with or without porcelain veneer masking layer) to the precise shape and position of an abutment. **Zirconia** is available in different shades to facilitate colour matching with the surrounding dentition. Furthermore, both titanium and zirconia can be used as a **mono-block abutment crown**, incorporating both the abutment and final restoration into a single entity to restore implants.

Key points

- Implant abutments provide support for the definitive restoration(s).
- Abutments are linked to the underlying implant fixture by either an external or internal connection.
- Customised, CAD/CAM abutments fabricated from titanium or zirconia are the most popular for restoring implant(s).

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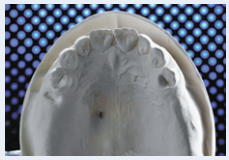
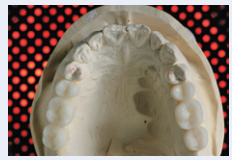
55 Restorative options

Transferring data


Preoperative


Wax-up

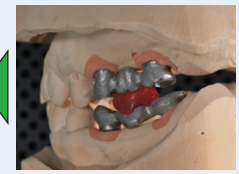
Stent

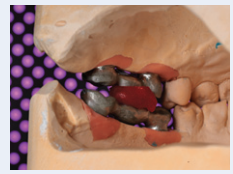
Healing caps

Fixtures

Imp. copings

Impression

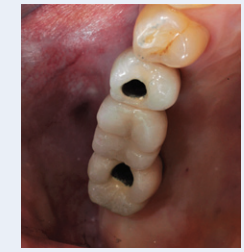

Framework

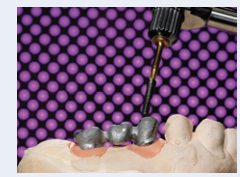

Framework

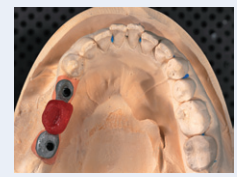
Postoperative

Fixed screw-retained

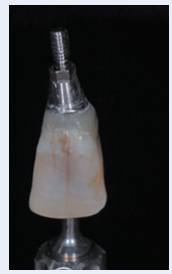
Fixed cement-retained


Definitive FPD


Screw


Screw holes

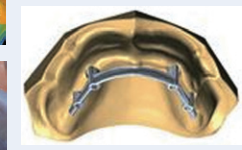
Location jig


Titanium abutment

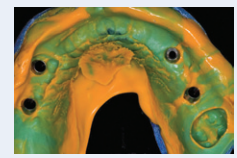
Defintive cement reatined crown

Maxillary IRO

Overdenture


Bar-clip retainer

Implants



Mandibular IRO

Overdenture

Ball abutments

Implants

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The final stage of implant rehabilitation is transferring the **intra-oral data** to the dental laboratory for the fabrication of the definitive restoration or prosthesis. The **definitive restoration** can be **fixed**, supported either solely by implants, or in combination with natural teeth abutments. A **removable prosthesis** is supported by implants, with or without soft tissue support. The decision of the definitive restoration is made at the **treatment planning stage**, and determines the type, number and positioning of the fixtures and abutments for supporting the final restoration(s).

Transferring data

Following successful osseointegration, the **intra-oral data** needs to be transferred to the dental laboratory for **prosthetic rehabilitation** of the implant fixtures. The intra-oral data includes the number, location, size and angulation of implants together with surrounding soft tissues and the adjacent and opposing dentition. This is accomplished by taking an **impression**, **face-bow** and **occlusal records**. At present, the analogue method is the most popular, using PVS or polyether impression materials in a custom-made tray, but in future will be replaced by **digital intra-oral impressions**.

The **analogue method** involves using **impressions copings** (made of plastic, titanium or anodised aluminium), which can be for **closed** or **open impression trays** (the latter if the angle of the fixture(s) is anticipated to hinder withdrawal of the tray). In the dental laboratory, a stone model is poured using the corresponding **implant analogues** (made of stainless steel or brass), in preparation for abutment fabrication. The contemporary method for designing both implant abutment(s) and the definitive restoration(s) is by **CAD/CAM technology**. Alternately, abutment(s) and restoration(s) can be waxed and cast using conventional prosthetic protocols.

Fixed cement-retained

Cement-retained restorations can be used for either single crowns or multiple-unit FPDs. First, the abutment is screwed or tapped onto the implant fixture, and second, the final restoration is subsequently cemented onto the abutment. Cement-retained restorations are recommended for:

- **Single anterior** crowns for optimal aesthetics, especially **all-ceramic** units that can be adhesively bonded to an underlying ceramic (e.g. zirconia) abutment with self-adhesive resin cements;
- **Severely misaligned implants** to compensate for poor **emergence profile**;
- **Facially located screw access** holes compromising aesthetics;
- **Screw access and sealing fillings** interfering with occlusal stability;
- **Thin biotypes** predisposed to gingival recession;
- **Limited interocclusal** clearance for accessing screw hole(s);
- **Narrow-diameter crowns** with inadequate width for placing screws.

A major problem with cement-retained restorations is **gaining access** to the **abutment-retaining screw** if **screw loosening** is suspected, which may require damaging the definitive restoration, particularly for **cemented multiple-unit FPDs**. Another concern is **deep subgingival margins (>3 mm)**, making cement removal difficult.

Fixed screw-retained

Screw-retained restorations are also suitable for both individual crowns and FPDs. The **abutment and crown (or FPD) is combined into a single prosthetic componen**t, avoiding different material interfaces, giving increased strength and stability and eliminating cement remnants. The **major benefit** is retrievability, and the current trend is to use screw-retained restorations, especially for posterior single units and full-arch fixed reconstructions. Also, a **small inter-arch space** may reduce retention and resistance of a cemented restoration; if clearance allows, a screw-retained restoration provides superior long-term retention.

The **drawbacks** of **screw-retained restorations** are:

- **Implant head requires vertical orientation**, for anterior restorations the screw location should be in line with the incisal edge, and for posterior units towards the central fossa;
- **Poor aesthetics** if screw hole is incorrectly positioned, or requires masking with an opaquer;
- **Micro-gap** between the abutment and crown is apical to the gingival crest, predisposing to chronic gingival inflammation.

To conclude, the **choice between a cemented** or **screw-retained restoration** is empirical, depending on the clinician's experience and preference and the prevailing clinical scenario. Research shows **little difference between the two types of restorations** with regard to peri-implant inflammation, marginal bone loss, or implant survival or success rates.

Implant-retained overdentures

Fixed implant-supported prostheses necessitating **multiple implants** may be contraindicated for several reasons including extensive bone grafting, anatomical obstacles, occlusal problems, elderly or infirm patients not able to tolerate protracted treatment sessions, and fiscal constraints. In these circumstances, removable **implant-retained overdentures (IRO)** provide improved retention, stability, aesthetics, phonetics, mastication and quality of life. IROs can either be **entirely implant-supported**, or a combination of **mucosa-supported and implant-supported**. A few strategically placed implants support an overdenture with either a **ball abutment with O-rings**, **magnetic** or **tower abutments**, **bar-clip retainer** with corresponding **female matrices** on the **fitting surface** of the prosthesis. Bar retainers are particularly useful for non-parallel implants.

For the **edentulous mandible**, usually **2 or 4 implants** are placed in the **interforaminal region**, while for the **maxilla 2 or 4 implants** in the **canine and second premolar regions** support a retentive bar-clip attachment. Furthermore, if conventional-diameter implants greater than 3 mm are not feasible due to inadequate bone width, **small-diameter implants (SDIs)** or **'mini-implants'** (1.8–2.9 mm) provide a conservative, minimally invasive alternative.

Key points

- Transferring intra-oral data requires taking an analogue or digital impression for fabricating the abutment and restoration.
- Fixed individual or multiple unit prostheses can be either cement- or screw-retained.
- Implant-retained overdentures provide an alternative to fixed units, especially using mini-implants.

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